AD-A126 317 VIBRATION AND AEROELASTIC FACILITY(U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH P G BOLDS DEC 82 AFWAL-TR-82-3054 1/2

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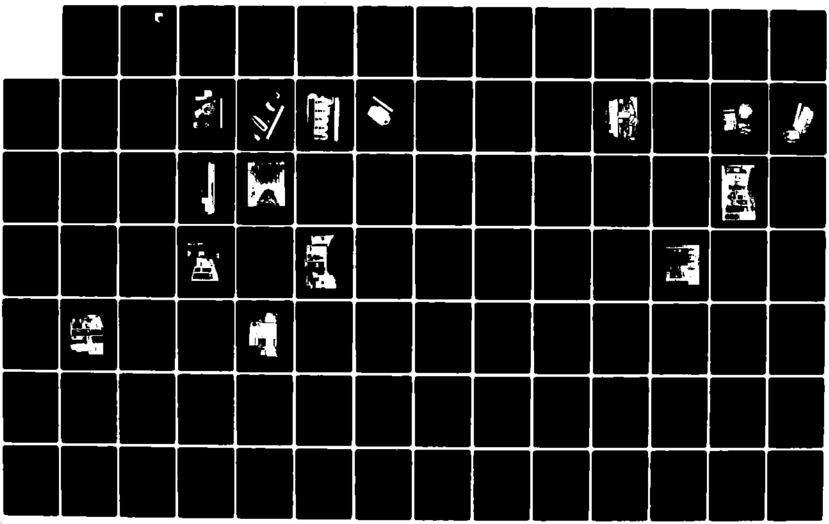

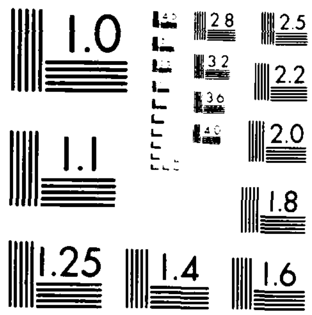

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VIBRATION AND AEROELASTIC FACILITY

Phyllis G. Bolds

Structural Vibration Branch
Structures and Dynamics Division

December 1982

Final Report for Period January 1977 - December 1981

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FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AFWAL-TR-82-3054	2. GOVT ACCESSION NO. AD-A126 317	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) VIBRATION AND AEROELASTIC FACILITY		5. TYPE OF REPORT & PERIOD COVERED Final Report Jan 77 to Dec 81
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Phyllis G. Bolds		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Flight Dynamics Laboratory (AFWAL/FIBG) Air Force Wright Aeronautical Laboratories Wright-Patterson Air Force Base OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 62201F 24010406
11. CONTROLLING OFFICE NAME AND ADDRESS Flight Dynamics Laboratory (AFWAL/FIBG) Air Force Wright Aeronautical Laboratories Wright-Patterson Air Force Base OH 45433		12. REPORT DATE December 1982
		13. NUMBER OF PAGES 100
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approval for public release;
distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Laboratory Test Facilities
Test Equipment
Analysis of Dynamics Measurement
Acoustics
Vibration
Pressure
Temperature

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Vibration and Aeroelastic Facility of the Air Force Wright Aeronautical Laboratories is used for recording and analyzing dynamics data. New instrumentation systems have made possible a significant increase in the quantity of measurements which can be acquired to define the dynamics environment in various aircraft, missile, and ground support equipment. To reduce the large quantities of data to a usable form, processing techniques based upon the use of spectrum analyzers and minicomputers are employed. These techniques are described and methods are illustrated for presenting statistical quantities defining the spectral composition of dynamics environments.

FOREWORD

This report was prepared in support of Project 2401, "Structures and Dynamics"; Task 240104, "Vibration Prediction and Control, Measurement, and Analysis"; and Work Unit 24010406, "Analysis Development for Data Reduction"; Flight Dynamics Laboratory; Air Force Wright Aeronautical Laboratories (AFWAL); Structural Vibration Branch (FIBG), Wright-Patterson Air Force Base Ohio. The evaluation was conducted during the period of January 1977 through December 1981.

The author wishes to thank Jack Schmermund for his assistance in obtaining the necessary photographs, Janice Chinn and Monica Lippolis for compiling the Bibliography, V. R. Miller, P. S. Hall, and D. E. Holsapple for editing of the technical report and Mr Robert Merkle who prepared the test plan outline. Acknowledgment is also given to Diana Howdyshell for typing the manuscript.

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SECTION I
INTRODUCTION

The Vibration and Aeroelastic Facility (VIAER) provides comprehensive support for the rapid acquisition and analysis of dynamics data. These data form the basis for solutions to system dynamics problems encountered both in service and during the research and development phase. The objective of this report is to discuss equipment and techniques associated with data acquisition, reduction, analysis, and interpretation.

During the past 15 years, the scientific community has experienced a digital revolution. Rugged, low-cost, mini-computer based data acquisition and analysis systems have replaced analog concepts and introduced new data analysis procedures. This report will describe the equipment and techniques which have made possible these advancements as well as proposed VIAER Facility improvements.

The measurement and analysis support of the Vibration and Aeroelastic Facility are available to all government agencies. Support may also be made available to industry when the work directly supports government programs.

Work may be done for commercial or nonmilitary purposes. Support performed of this nature must be in the public interest and sponsored by Federal Executive Agencies exclusive of DoD agencies.

SECTION II
DATA ACQUISITION CAPABILITY

The VIAER Facility has the capability for measuring dynamics parameters such as acceleration, velocity, displacement, strain, sound pressure, pressure, and temperature. It provides custom, complex instrumentation packages for the space and parameter requirements of a specific test.

The acquisition equipment includes a wide selection of modern dynamics transducers, signal conditioners, and tape recorders. In addition, the VIAER Facility has available two mobile data acquisition and analysis vans which are completely self-sufficient and capable of operating at the remotest of test sites throughout the continental United States.

The group responsible for the acquisition of dynamics data maintains state-of-the-art equipment as well as technical expertise in the field of in-flight and structural vibration excitation. The process of obtaining dynamics data and storing it for subsequent retrieval and processing can be summarized into five major tasks: transduction, signal conditioning and power supply, recording, data verification, and record keeping. A block diagram of the dynamics data acquisition is shown in Figure 1.

1. TRANSDUCTION

This effort assures the proper selection of a transducer which will transform the desired dynamics phenomena into an energy form which is more easily measured, usually an electrical signal. Proper transducer selection will assure that a minimum amount of energy is consumed in the conversion process and that the transducer range is sufficient for the measurements. The transfer function characteristics of the transducer must be known to permit absolute quantities to be determined during subsequent processing. Time code and voice communication is also recorded to aid in the editing of the data. The specifications of typical VIAER transducers are given in Table 1. A photograph of each type of transducer is shown in Figures 2-5.

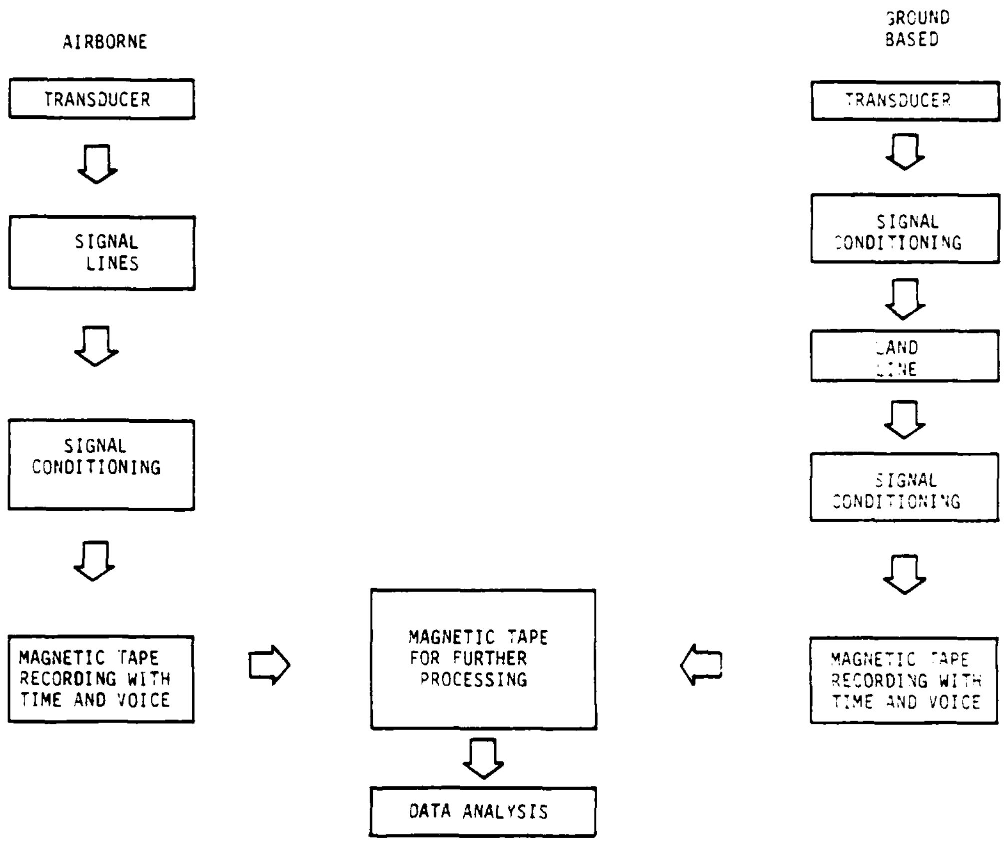

Figure 1. Block Diagram of the Dynamics Data Acquisition Procedure

TABLE 1

SPECIFICATIONS FOR VIAER TRANSDUCERS AND SIGNAL CONDITIONING

Piezoelectric Accelerometers

Columbia Research Labs Model 902H
- Frequency Range: 1 Hz to 6 KHz
- Resonant Frequency: 32 KHz nominal
- Maximum Acceleration: 2000G
- Size: 5/8" hex x 0.8" high
- Weight: 31.5 grams
- Temperature Range: -65°F to 350°F or 500°F

Columbia Research Labs Model 860-1
- Frequency Range: 1 Hz to 7 KHz
- Resonant Frequency: 35 KHz
- Maximum Acceleration: 1000 G sinusoidal
- Size: 3/8" hex x 0.225" high, excluding connector
- Weight: 2.8 grams
- Temperature Range: -100°F to +350°F

Columbia Research Labs Model 606-2
- Frequency Range: 1.5 Hz to 8 KHz
- Resonant Frequency: 40 KHz
- Maximum Acceleration: 2000 G peak sinusoidal
- Size: 0.275" hex x 0.22" high
- Weight: 1.5 grams
- Temperature Range: -100°F to 350°F

Bolt, Beranek, and Newman Model 501
- Frequency Range: 8 Hz to 20 KHz
- Resonant Frequency: 90 KHz
- Maximum Acceleration: 200 G peak
- Size: 0.312" dia. x 0.330" high
- Weight: 1.8 grams
- Temperature Range: -65°F to +250°F

Vibra-Metrics Model M1000
- Frequency Range: .3 to 35 KHz
- Resonant Frequency: 80 KHz
- Maximum Acceleration: 400 G
- Size: .25" x .396"
- Weight: 2 grams
- Temperature Range: -65°F to +250°F

Vibra-Metrics Model M1020
- Frequency Range: .3 to 25KHz
- Resonant Frequency: 50 KHz
- Maximum Acceleration: 40 G
- Size: 1.14" x .75"
- Weight: 39 grams
- Temperature Range: -65°F to +250°F

TABLE 1 (Continued)

Capacitance Accelerometers

- Setra Model 106
  - Frequency Range: 0 to 300 Hz minimum
  - Resonant Frequency: 1550 Hz
  - Maximum Acceleration: ±25 G
  - Size: 1¼" x 1¼" x 1¼"
  - Weight: 3½ ounces
  - Temperature Range: -65°F to +210°F

Servo Accelerometers

- Gulton Model LA 550203
  - Frequency Range: 0 to 30 Hz
  - Resonant Frequency: 130 Hz
  - Maximum Acceleration: ±10 G
  - Size: 1.2" x 1.2" x 3.4"
  - Weight: 5½ ounces
  - Temperature Range: -65°F to +212°F
- Columbia Research Labs Model SA-102D
  - Frequency Range: 0 to 100 Hz
  - Resonant Frequency: 200 Hz
  - Maximum Acceleration: ±10 G
  - Size: 1.5" x 1.8" x 3"
  - Weight: 5 ounces
  - Temperature Range: -40°F to +200°F

Piezoelectric Microphones

- Gulton Model MVA 2100
  - Frequency Range: 2 Hz to 6 KHz
  - Resonant Frequency: 27 KHz
  - Dynamic Range: 110 to 190 dB SPL
  - Size: 0.76" dia x 0.82"
  - Weight: 0.75 ounces
  - Temperature Range: -65°F to +250°F
- Gulton Model MVA 2400
  - Frequency Range: 2 Hz to 20 KHz
  - Resonant Frequency: 100 KHz
  - Dynamic Range: 110 to 190 dB SPL
  - Size: 0.36" dia x 0.6"
  - Weight: 3.5 grams
  - Temperature Range: -65°F to +250°F
- Gulton Model 199513 (3 transducers per block)
  - Frequency Range: 10 Hz to 60 KHz
  - Resonant Frequency: 300 KHz
  - Dynamic Range: 110 to 190 dB SPL
  - Size: 3/8" x ½" x 1"
  - Weight: 0.75 ounces
  - Temperature Range: -65°F to +250°F

TABLE 1 (Continued)

Condenser Microphones
- Bruel & Kjaer Model 4136
  - Frequency Range: 5 Hz to 70 KHz
  - Dynamic Range: 55 to 176 dB SPL
  - Size: 0.275" dia x 0.41" plus preamp
- Bruel & Kjaer Model 4134
  - Frequency Range: 5 Hz to 20 KHz
  - Dynamic Range: 30 to 160 dB SPL
  - Size: 0.52" dia x 0.5" plus preamp
- Bruel & Kjaer Model 4145
  - Frequency Range: 3 Hz to 18 KHz
  - Dynamic Range: 15 to 146 dB SPL
  - Size: 0.93" dia x 0.75" plus preamp

Eddy Current Microphones
- Kaman Sciences Corporation
  - Frequency Range: DC to 6.1 KHz
  - Dynamic Range: 118 to 182 dB SPL
  - Size: 0.5" dia x 0.676" plus cable
  - Temperature Range: 25°C to 1093°C

Pressure Transducers (Strain Gage)
- Bell & Howell Model 4-312-0002
  - Frequency Range: DC to 1 KHz
  - Pressure Range: ±5 PSID
  - Size: 0.5" dia x 0.68" plus connector
  - Temperature Range: -65°F to +260°F

Thermocouple Conditioning Unit
- Consolidated Ohmic Devices Model SCT-904D
  - Output Voltage: 0 V to 5 VDC (-60°C to +900°C)
  - Reference Junction: -60°C
  - Thermocouple Material: iron-constantan
  - Size: 2" x 3" x 4"

Amplifiers, Automatic Gain Changing
- Intech Model A-2318 (card) and A-2319 (packaged)
  - Gain Range: -10 to +60 dB
  - Configuration: AC or DC, single ended or differential
  - Input Impedance: 100 megohms minimum
  - Gain Status: DC voltage proportional to gain step
  - Configuration: automatic setting, preset, or inhibited
  - Power: A-2319 - ±15 VDC
A-2318 - ±15 VDC, +5 VDC
  - Size: A-2319 - 1-1/2" x 2-7/8" x 4"
A-2318 - 3/4" x 4" x 5"

TABLE 1 (Concluded)

Power Supplies
CEA Model CEAD60150Y
Input Voltage: 115 VAC. 60 to 400 Hz
Output Voltage: ±15 VDC, ±2.5 amperes
Size: 5½" x 7" x 7"
Weight: 18 pounds

Power Cube Models 24G100, 5TR65, 15TR35
Input Voltage: 24-32 VDC
Output Voltage: +5 VDC, 6.5 amperes
+15 VDC, ±3.5 amperes
Size: 1-1/2" x 6-3/8" x 7-1/2"
Weight: 2 pounds

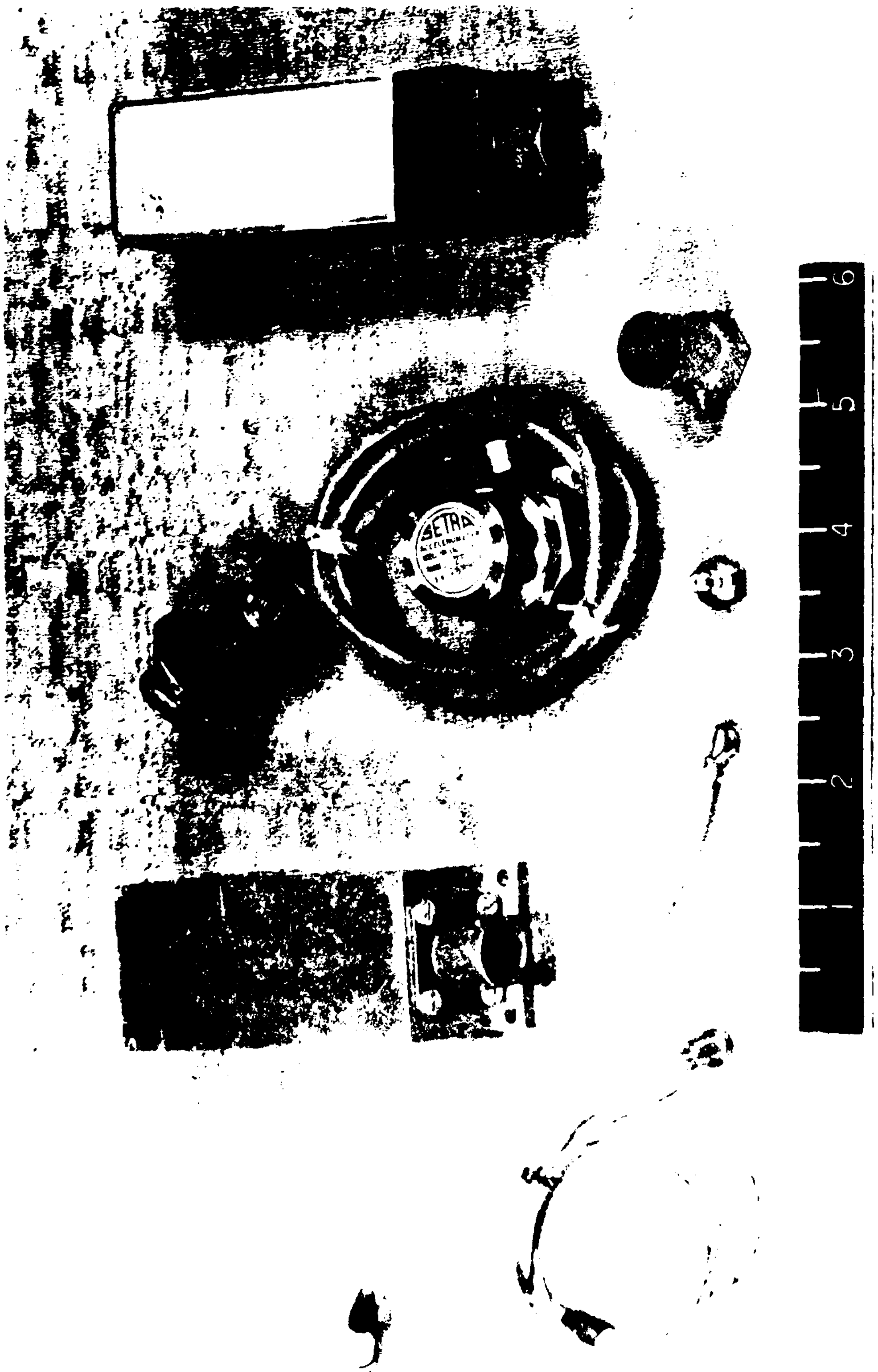

Figure 2 Types of Accelerometers

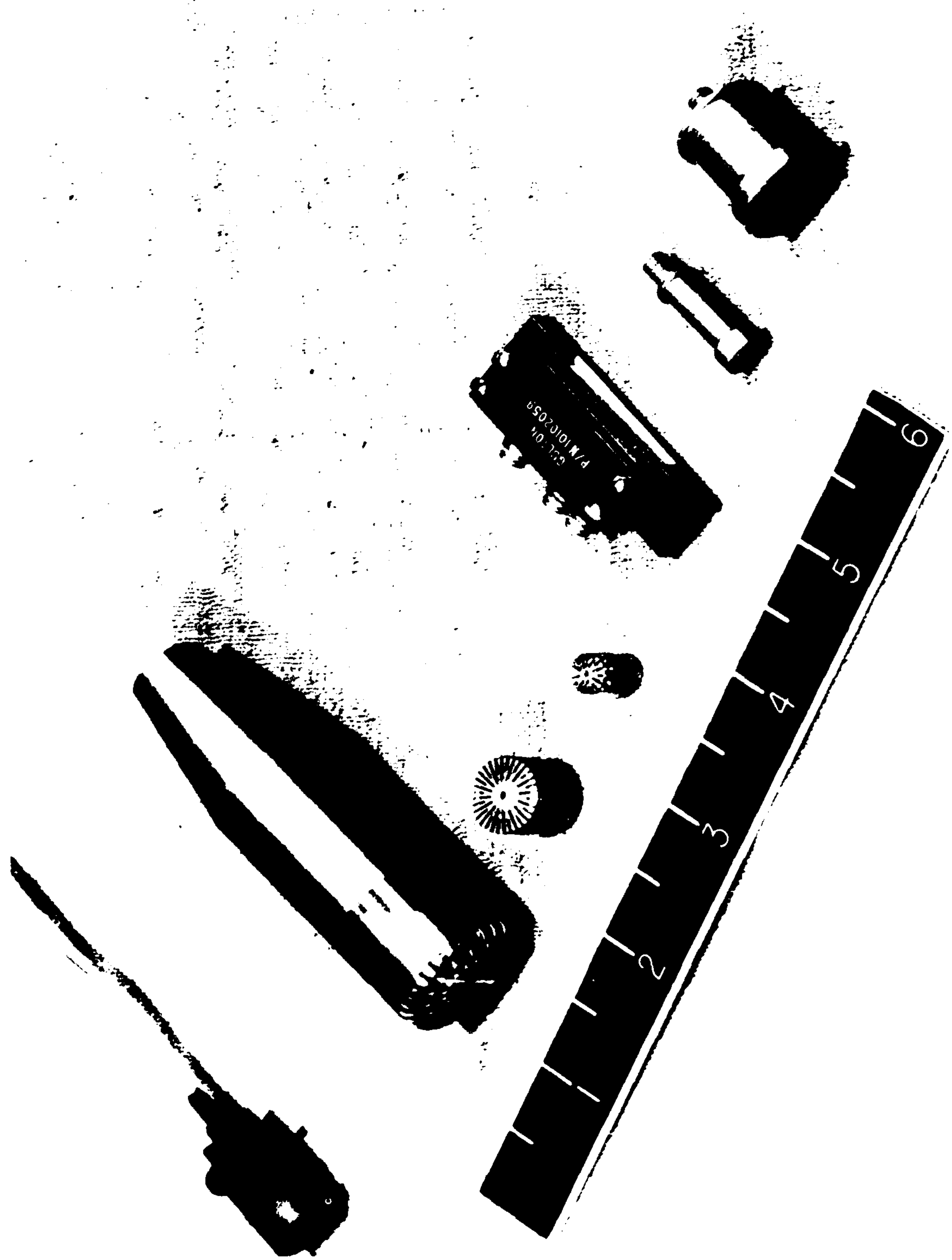

Figure 3. Types of Microphones

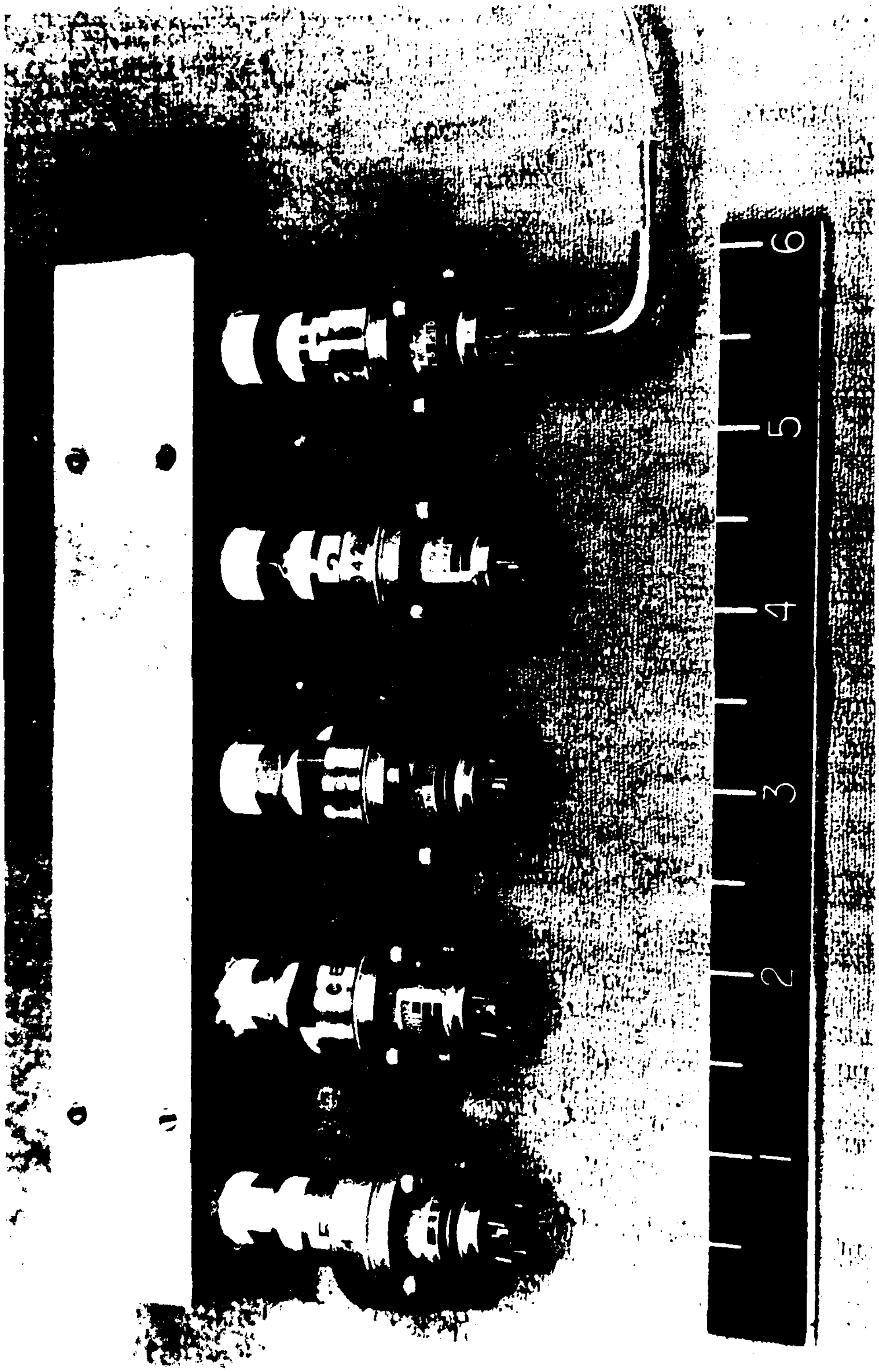

Figure 4. Types of Pressure Transducers

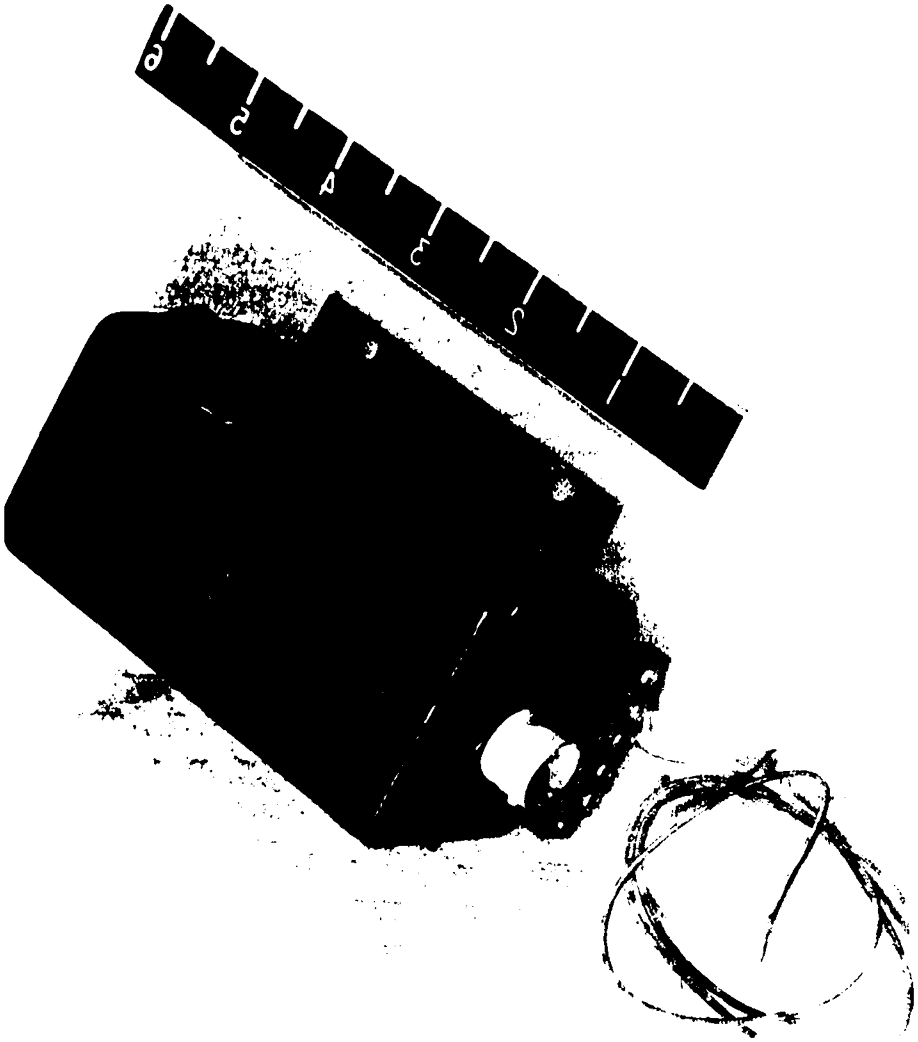

Figure 5. Thermocouple with Amplifier

2. RECORDING

Storage of this data in the analog time history realm is accomplished by using magnetic tape recordings, usually by frequency modulation (FM). This method provides data over the frequency range of DC to some frequency determined by the tape speed. Sampled data is recorded by direct recording for Pulse Code Modulation (PCM), or frequency modulation (FM) for Pulse Amplitude Modulation (PAM). Portable ground or flight package is one of the types of data recording systems used at the VIAER Facility. These modular packages can be constructed in any special configuration required. The system contains a 12-channel, low-pass filter module, a master amplifier unit, auxiliary amplifier unit, time code generator, input cable junction box, and 14-data channel plus two edge tracks airborne tape recorder. The power supplies for the system are installed under the master amplifier unit. The modular system concept provides the capability for quick response to signal recording needs. Additional amplifier units may be added as required. Each additional unit contains seven amplifiers which may be set at a preselected gain or allowed to step to the proper recording level for the tape system. One card slot in each amplifier unit is capable of accepting an integrator card permitting integration of all signals within that amplifier unit. The master amplifier unit also contains a Pulse Amplitude Modulation (PAM) commutator system and a voice annotation amplifier.

The PAM system permits recording of the amplifier gain status, as well as up to 43 additional low-frequency data signals. The tape system is a multi-speed FM transport using one-inch tape. Voice annotation can be put on edge tracks or data tracks. The PAM output is recorded on a data track, allowing up to 13 additional data signals to be recorded. Low-pass filters can be added or deleted and automatic selection of input signals can be accomplished by incorporating a step switch in the input cable junction box. The system will operate from 28 VDC, 12 VDC, or 115 VAC at 60 or 400 Hz. Specifications and a photograph of the portable data recording system are contained in Table 2 and Figure 6, respectively.

TABLE 2

SPECIFICATIONS FOR PORTABLE DATA RECORDING PACKAGE

Automatic Gain Changing Amplifiers, Intech Model 2318
- Input Configuration: AC or DC coupled, single ended or differential
- Input Impedance: 100 megohms minimum
- Pass Band: DC to 20 KHz
- Gain Steps: 10 dB, from -10 dB to +60 dB

Filters
- Configuration: low pass
- Attenuation Rate: 48 dB per octave
- Cutoff Frequencies: 30 Hz, 80 Hz, 160 Hz, 320 Hz, custom

Commutator, Vector Model CSV-100
- Configuration: single ended, pulse amplitude modulation, return to zero
- Frame Size: 60 segments, less 2 for synchronization and 1 for zero level calibration
- Frame Rate: 60 frames per second maximum, divider for 30, 15, 7½, 3-3/4, 1-7/8, and 15/16 frames per second
- Input Level: ±2.5 VDC for 0% to 100% of signal range
- Input Impedance: 10 megohms minimum

Time Code Generator, Datametrics Model SP 105
- Output Code: IRIG "B"
- Reset-Preset: automatic reset at power application, start time 00 hrs, 00 min, 00 sec

Power Supply, Power Cube Corporation
- Generator 24G100W40
  - Input Voltage: 24-32 VDC
  - Output Voltage: 40V pk, 20 to 60 KHz square wave
  - Size: 1" x 1" x 2"
- Output Converter, 5TR65
  - Input Voltage: 40V pk, 20 to 60 KHz square wave
  - Output Voltage: 5 VDC regulated
  - Output Current: 6.5 amps
  - Size: 1" x 2" x 2"
- Output Converter, 15TRC10
  - Input Voltage: 40V pk, 20 to 60 KHz square wave
  - Output Voltage: ±15 VDC regulated
  - Output Current: 1.0 amp
  - Size: 1" x 1" x 2"

Tape Recorder, Leach Model MTR 3200A
- Record: intermediate band FM
- Number of Tracks: 14 data tracks plus 2 edge tracks

TABLE 2 (Concluded)

Tape Speeds: six, selectable in pairs with belt change between
pairs: 60-30, 15-7½, 3-3/4 - 11-7/8
Tape Width: 1 inch
Reel Size: 8 inch NAB hub
Recording Time at 15 ips: 32 minutes

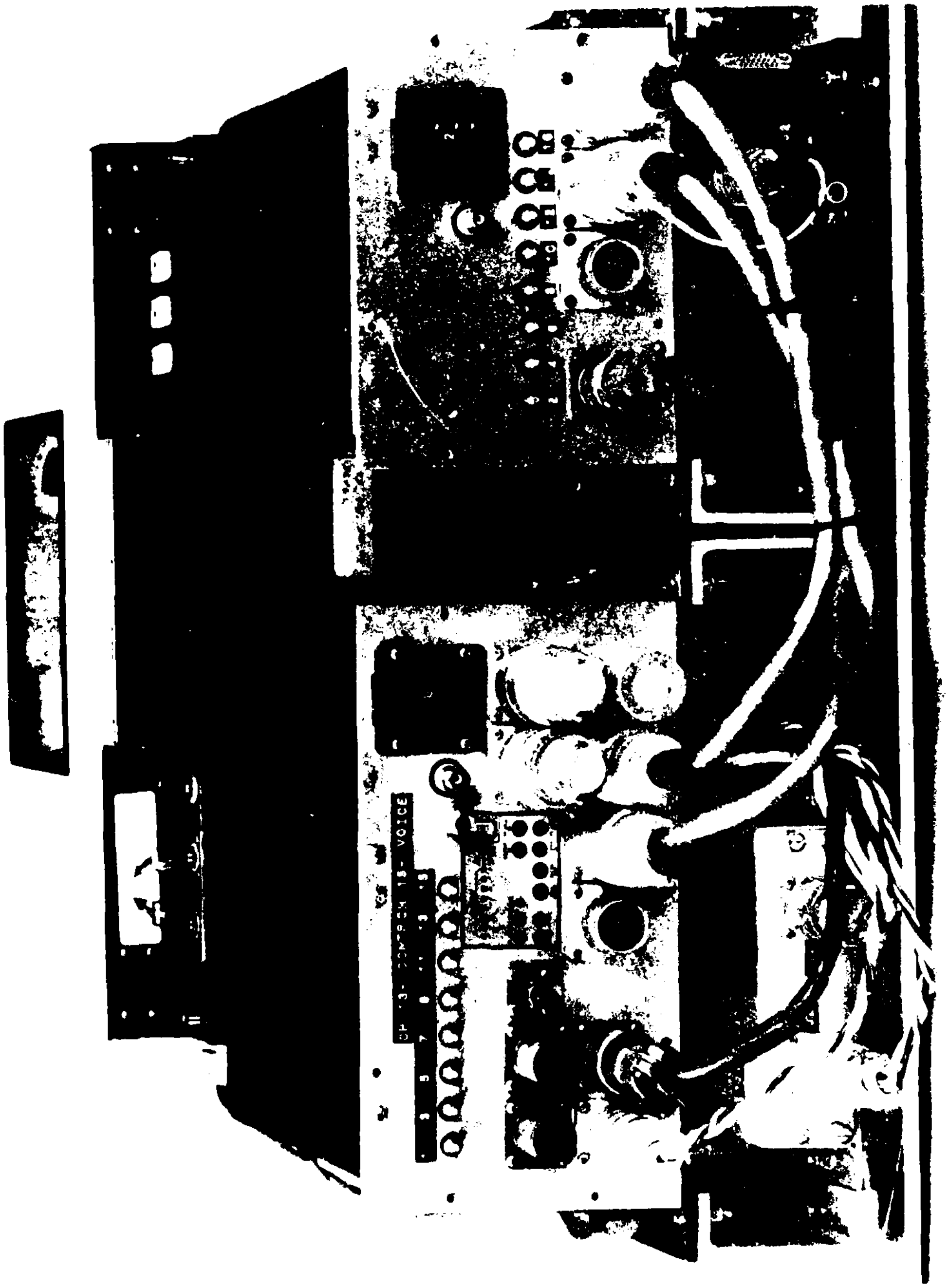

Figure 6. Portable Data Recording System

The transducers required for any particular measurement can be selected from these types. The accelerometers cover the frequency range of DC to 40 KHz, and amplitude range from the noise floor typically 10^{-3}G to 2000G. The microphones cover a frequency range of 3 Hz to 20 KHz and an amplitude range of 15 dB Sound Pressure Level (re 0.00002 Pa) to 190 dB SPL. The pressure transducers are strain gage units which are Pounds/Square Inch Differential (PSID) sensors. Their maximum limit is $\pm$7.5 PSI and they have a frequency range of DC to 1 KHz. Other pressure ranges are available. The thermocouple unit is a DC amplifier with integral thermocouple reference junction. It provides a $\pm$5 VDC output.

3. SIGNAL CONDITIONING AND POWER SUPPLIES

Most transducer signal conditioning is accomplished with the INTECH Automatic Gain Changing (AGC) amplifier printed circuit cards shown in Figure 7. The AGC amplifiers are used in both airborne and ground data acquisition packages. In a typical application, six AGC cards are placed in a secondary amplifier unit for a total of 12 signal conditioned data channels. For a given transducer, the AGC amplifier automatically selects the gain required (from -10 dB to 60 dB in 10 dB increments) for presenting an optimum voltage level signal to the Leach tape recorder. A commutator in the master amplifier samples gain status voltages from each of the 12 AGC amplifiers. The amplifiers can be set for automatic gain or fixed gain. An inhibit option allows remote fixing of amplifier gains during the test.

In addition to the AGC amplifiers, there are special conditioning cards and modules utilized for impedance translation, amplification, filtering, strain gage conditioning, integrating, and pulse code modulation (PCM). The two versions of power supplies are shown in Figure 8. The unit on the left accepts a 28 VDC input and provides the required $\pm$15 VDC and +VDC required for the signal conditioning equipment. The unit on the right accepts a 115 VAC 60/400 Hz input power and then provides the $\pm$15 VDC and +5 VDC required.

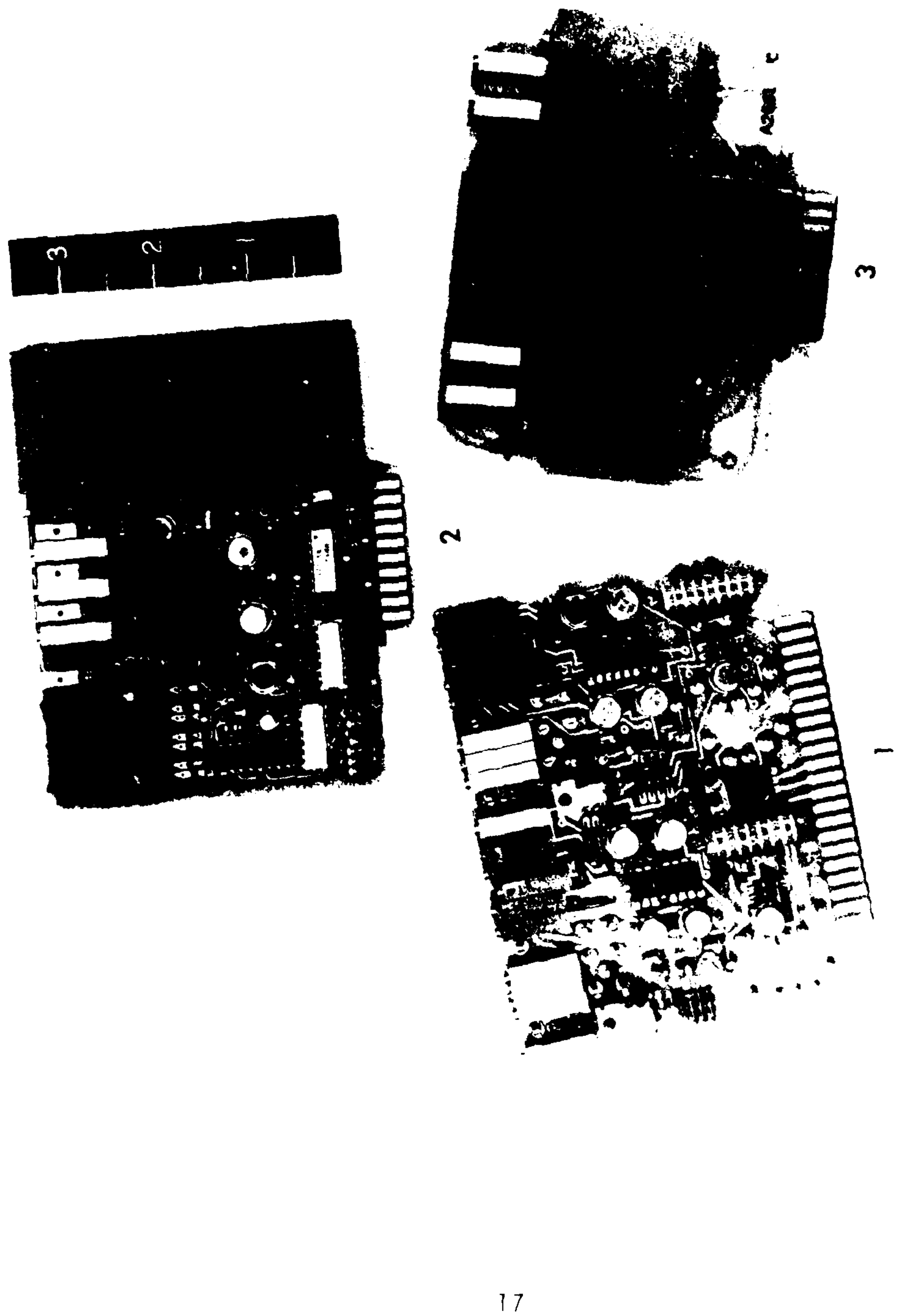

Figure 7. Types of Signal Conditioners for Transducers

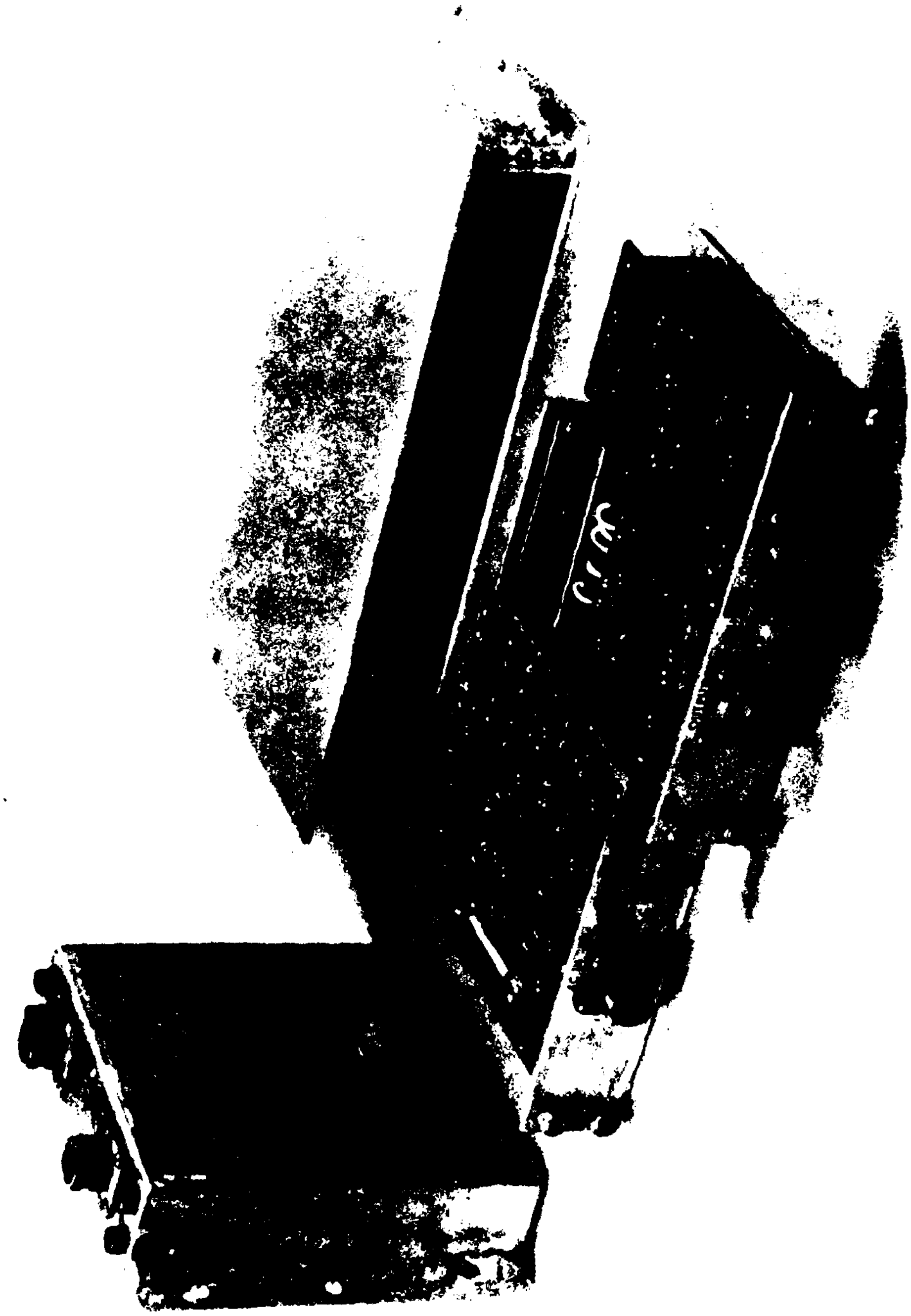

Figure 8. Power Supplies

The VIAER Facility has two data acquisition and analysis vans. These vans are used to record dynamics phenomena where many channels (up to 36) of broad-band data are simultaneously required. The vans are completely self-sufficient and capable of generating all electrical power required for operation, or they can use commercial power if available. The vans provide a capability for complete dynamics data coverage at any remote test site within the continental United States, as well as at Government or commercial sites where data acquisition and analysis capability is limited. The instrumentation vans are primarily for dynamics data acquisition and preliminary analysis; however, present signal conditioning permits recording of most types of transducer outputs. The dynamics transducers generally used are piezoelectric, servo, and capacitive accelerometers, as well as both piezoelectric and capacitive microphones. Each van contains 36 land lines, each 457.2m (approximately 1500 feet) in length, that are connected through external amplifiers to remotely located transducers. The external amplifiers provide impedance conversion from high (transducer output) to low (line driver) for routing to the van through the land lines. The external amplifiers have gain capability of -10 dB to +60 dB, and can be configured to step automatically as a function of the signal level. Internal amplifiers are provided to permit further adjustment of the signal level. Viewing of the data is possible with monitor oscilloscopes. Three magnetic tape transports, each capable of 14 data channels and 2 edge tracks, are provided for recording data, annotation, time signals, and amplifier gain status. The specifications and external and internal photographs of the van are contained in Table 3 and Figures 9 and 10, respectively.

4. DATA VERIFICATION

This task is accomplished in the field or immediately after a flight to be sure that the data has been properly recorded and aid in the determination of additional test or flight requirements. The tape is played back and each tape channel is viewed on an oscilloscope and/or narrowband and one-third octave real-time spectrum analyzers may be used.

TABLE 3

SPECIFICATIONS FOR VANS

Land Lines
36, each 1500 ft long, 4-conductor, shielded, #20 wire with Teflon insulation and Teflon outer covering

Internal Amplifiers, Intech Model A2583
Input Configuration: AC or DC coupled, single ended or differential
Mode: automatic, manual, inhibited
Pass Band: DC to 10 KHz minimum
Gain Status: analog voltage to commutator plus indicator lamps on auxiliary panel

Monitor Oscilloscopes, Calico Model 7000
Viewing Area: 1" x 3", 3 sq in
Band Width: DC to 5 MHz
Sensitivity: 0.1 to 10 V rms/inch
Total Channels: 14

Time Code Generator, Systron Donner Model 8350
Output Code: IRIG "B"
Display: hours, minutes, seconds
Time Preset: hours and minutes
Read Code: IRIG "B" forward direction only

Oscillograph, Honeywell Model 1508
Paper Width: 8 inches
Recording Paper: direct write from fiber-optic cathode ray tube
Paper Speeds: 0.1 to 120 inches per second
Number of Channels: 13 plus numeric time of day

Narrow-Band Analyzer, Nicolet Scientific Model UA500
Frequency Range: 10 Hz to 100 KHz
Input Signal Range: 1.1 VRMS to 10 VRMS, single channel
Memories: 2 memories plus instantaneous spectrum
Number of Frequency Points: 500
Displays: X-Y plotter and oscilloscope

1/3 Octave Band Analyzer, Spectral Dynamics Model SD312
Frequency Range: 3.15 Hz to 20 KHz in 39 1/3 octave bands plus overall
Dynamic Range: 60 dB
Weighting: A, B, C, D or flat
Outputs: self-contained CRT and X-Y plotter
Integrating Times: 0.5 to 64 seconds

Magnetic Tape Recorders, Honeywell Model 96
Record/Reproduce: low, intermediate, Wide Band I-FM
Wide Band II-direct
Number of Tracks: 14 data plus 2 edge tracks

TABLE 3 (Concluded)

Tape Speeds: nine, 15/16 ips to 240 ips
Tape Width: 1 inch
Reel Size: NAB precision up to 16-inch

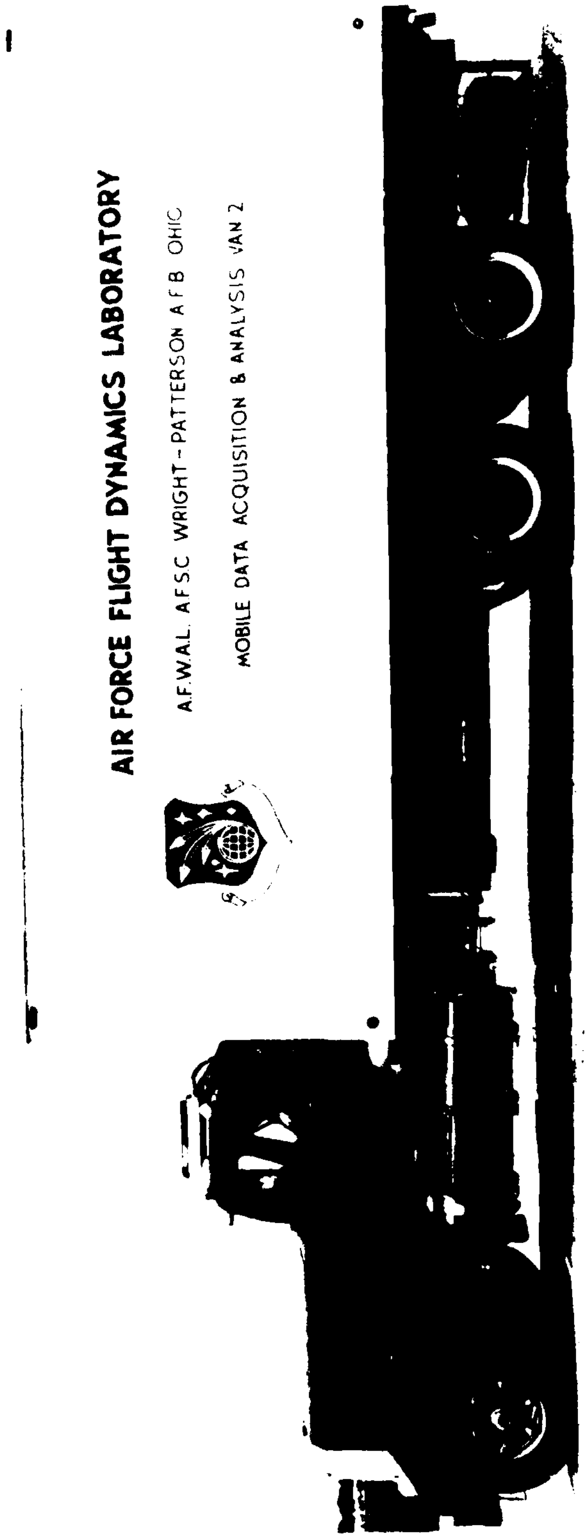

Figure 9. Data Acquisition Van

Figure 1.[illegible] Inside Data Acquisition Van

5. RECORD KEEPING

The data tapes are then labelled as to flight or test location, date, channel identification, transducer sensitivity, and gain settings are also maintained with the tapes. All information required for processing and test condition identification is included to ensure absolute value determination in the subsequent processing.

SECTION III
DATA ANALYSIS CAPABILITY

The VIAER Facility provides the overall capability for the recovery and analysis of dynamic measurements. These capabilities are required to accurately describe the operating environment of flight vehicles and to assess the accuracy of analytical prediction methods. The Air Force Wright Aeronautical Laboratories has developed the facilities and expertise for recovering, reducing, analyzing, and graphically displaying a wide range of dynamics data measured inflight (or on the ground) and in the laboratory. The process for transforming the dynamics data from the raw form on magnetic tape into a form that yields the information required by engineers and scientists consist of four major tasks: data recovery and editing, analog-to-digital conversion, statistical analyses, and graphic data presentation. A block diagram of the dynamics data analysis procedure is shown in Figure 11, and the input/output specifications are listed in Table 4.

1. DATA RECOVERY AND EDITING

The first step involves playing back raw data (analog) tapes through the necessary equipment such as FM discriminators, direct record reproducers, pulse amplitude modulation (PAM), and pulse code modulation (PCM) playback system in order to "recover" the data. During this operation, the analog signal is edited to check for bad data characteristics, such as clipping or loss of signal. The data records on the tape are compared with the voice track for test condition identification and the time code for time correlation purposes. The signal is traced by oscillograph with time code numerically displayed to investigate the time data in detail and to select precisely the areas for analysis. The oscillograph traces are marked with the proper gain factors induced by the automatic gain changing amplifiers. The time is selected for digitizing purposes, i.e., sample and hold start times to decrease the statistical error associated with cross channel analysis.

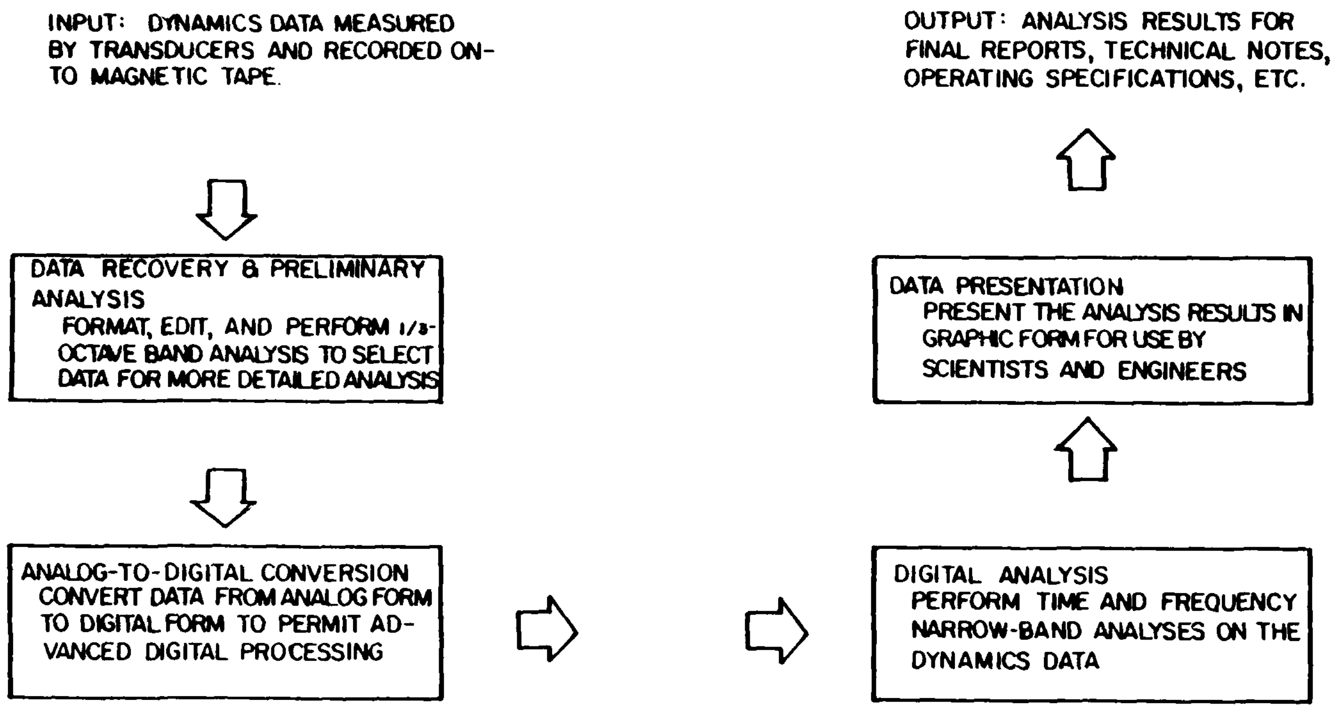

Figure 11. Dynamics Data Analysis Procedure Flow Chart

TABLE 4

INPUT AND OUTPUT SPECIFICATIONS

INPUT

Analog tape
- FM (intermediate band)
- Direct (intermediate or wide band)
- Pulse Amplitude Modulation (PAM), Pulse Code Modulation (PCM), and constant and/or proportional band-width subcarrier modes

Digital tape
- 7 or 9-track
- 200, 556 or 800 BPI
- ASCII or BCI format

Cards

Paper tape

OUTPUT

Oscillograph traces of signals, including numerical printout of time code
1/3 and 1/1-octave band analysis
Digital narrow-band analysis
Statistical analysis
Plots and lists of results

If it is desired to examine (or delete) a particular band of frequencies, the data signal may be filtered with low, high, or band pass analog filters. This decision is usually determined by a "quick look" at the data using an analog real-time spectrum analyzer and plotting the output on an X-Y plotter.

The results of this phase of data reduction is verification of the dynamics data and selection of the areas of interest for further analysis. The specifications and photograph of the data recovery and editing systems are listed in Table 5, and shown in Figure 12.

2. ANALOG-TO-DIGITAL CONVERSION (A/D)

The edited analog data are converted to digital form and stored on magnetic tape for computer processing. An example of how the digital parameters are derived is shown in Table 6. The digitizing parameters are limited by the analog tape speed, record length, and upper cutoff frequency. The secondary requirements are obtained by selecting the number of channels to be digitized simultaneously, and the delta frequency dictated by the purpose of the study. Sample and hold amplifiers are used to assure that the same time intervals are digitized simultaneously on each channel by using time code associated with all channels on the recorder. This narrow-band analysis initially involves sampling the analog signal at a predetermined time interval and converting each sample voltage to a binary number. There are several "rules" which must be followed during the digitizing process to maintain high accuracy and to avoid loss of information content. By the sampling theorem, the sampling interval must be less than the reciprocal of twice the highest frequency of interest to ensure complete reconstruction of the data in the selected frequency range. This leads to the requirement that "anti-aliasing" filters be applied to the data before sampling to prevent frequencies higher than the maximum frequency selected from aliasing or folding back about the Nyquist (maximum) frequency into the lower frequency range of interest. Once in digital form, the data can be processed by means of computer software. Another method of screening the data is using the rms software program to compute the rms of each

TABLE 5

SPECIFICATIONS FOR DATA RECOVERY AND EDITING SYSTEMS

Playback Systems
    FM Reproduce
        1. Intermediate Band (IRIG Intermediate)
            Tape Widths: 1/4", 1/2", 1"
            Tape Speeds: 1-7/8, 3-3/4, 7-1/2, 15, 30, 60, 120 ips
            Center Frequency, IRIG standard, extended, Wide Band 1
            Deviation up to ±40%
            S/N Ratio: minimum - 48 dB, speed and frequency dependent

        2. Wide Band (IRIG Wide Band Group II)
            Tape Width: 1"
            Tape Speeds: 15/16, 1-7/8, 3-3/4, 7-1/2, 15, 30, 60, 120, 240 ips
            Center Frequency: standard, extended, Wide Band 1, Wide Band II
            Deviation: up to ±40%
            S/N Ratio: minimum - 28 dB, speed and frequency dependent

    Direct Reproduce
        1. Intermediate (IRIG Intermediate)
            Tape Widths: ¼", ½", 1"
            Tape Speeds: 1-7/8, 3-3/4, 7-1/2, 15, 30, 60 120 ips
            Frequency Range: 200 Hz to 700,000 Hz, speed dependent
            S/N Ratio: minimum - 24 dB, speed and frequency dependent

        2. Wide Band (IRIG Wide Band Group II)
            Tape Width: 1"
            Tape Speeds: 15/16, 1-7/8, 3-3/4, 7-1/2, 15, 30, 60, 120, 240 ips
            Frequency Range: 50 Hz to 2 MHz, speed dependent

Data Recovery Systems
    Pulse Amplitude Modulation (PAM) System, IRIG Compatible
        Modes - 1 PAM - RZ, 10-50,000 channels/sec
                2 PAM - NRZ, 10-100,000 channels/sec
                3 PDM, 10-10,000 channels/sec
        Frame Length - 10 to 199 channels

    Pulse Code Modulation (PCM) System, IRIG Compatible
        Codes - NRZ-L, RZ bit rate 1 bps-5M bps
                NRZ-M, DM-M, word length 4-99 bits
                NRZ-S, DM-S, frame length, 3-999 words
                Bi-Phase-L, frame sync pattern: up to 33 bits
                Bi-Phase-M, subframe available
                Bi-Phase-S

TABLE 5 (Concluded)

Subcarrier Discriminator System

1. Proportional or Constant Bandwidth: IRIG compatible
2. Non IRIG Standard: Any subcarrier center frequency between 200 Hz and 1.999 MHz. Any deviation between ± 20 Hz and ± 800 KHz within a deviation percentage range of ± 4% to ± 40%.

Time Code Translator

Carrier Modulated, all types requiring modulation (No DC level change)

Standard Codes

IRIG A	NASA 28
IRIG B	XR3
IRIG E	2137
IRIG H	2137 (2 KHz)
IRIG G	1892
NASA 36	

Multi-Channel Filter System

Type: high, low, band, and notch pass filters
Maximum Number of Channels: 12
Roll Off: 48 dB per octave
Frequency Response: flat + 0.25 dB to f co
Cut-Off Frequencies: 60 low pass over the range of DC to 150 KHz
Ultimate Rejection: 80 dB attenuation, reference 10 V rms

Figure 12. Data Analysis and Recovery Equipment

TABLE 6

EXAMPLE OF DIGITIZING PARAMETERS

Density (Hi: Med: Lo: Best:) B:

Analog Tape Speed (IPS): 30:

Run Length (Seconds): 30:

Highest Frequency: 2000:

Number of Data Channels: 2:

Delta Frequency: (.001 for Lowest): 1:

How Many Transforms? (1: or Best:): B:

Strobe Rate:	15000.
Density (BPI):	800.00
Analog Tape Speed (IPS):	30.000
Number of Records:	256.00
Cut-Off Filter (Hertz):	2000.0
Digitizing Time (Seconds):	13.107
Highest Frequency:	2000.0
Scale Factor:	1.0000
Scan Size:	3.0000
Frame Size:	3.0000
Delta Frequency:	1.2207
Record Size:	768.00
Number of Transforms:	16.000
Transform Size:	4096.0
Cycles per Transform:	1633.4
Confidence (Cycles):	26214.
Samples per Cycle:	2.5000
Run Length (Seconds):	13.107
Data Throwaway (%):	.00000
Number of Data Channels:	2.0000
Harmonic Number:	15.339

record segment, and the gain changes versus time. The specifications and photograph of the A/D system is contained in Table 7 and Figure 13, respectively.

To obtain the frequency analysis of acoustic data, the analog tapes are fed into an octave/one-third octave band analyzer. In this type of analysis, the frequency range is divided into progressively wider bands which are a constant percentage (70% and 23%, respectively) of a set of center frequencies from 4 to 16 KHz for octave and 3.15 to 20 KHz for the one-third octave analyses. This type of analysis results in narrow bands at low frequencies but wide bands at higher frequencies. A photograph of the one-third octave analyzer is included in Figure 12.

3. DIGITAL ANALYSIS

The dynamics data in digital form can be processed by a computer-controlled analyzer, using the Fast Fourier Transforms (FFT) algorithm to perform narrow-band analysis. This includes time/frequency domain analyses such as:

Analysis	Typical Usage
Amplitude Spectra	Frequency content of acceleration data.
Power Spectra Density	Distribution of power throughout frequency range of acceleration and dynamic pressure.
Amplitude Probability Density	Probability of occurrence of extreme values for all types of dynamics data.

TABLE 7

SPECIFICATIONS FOR ANALOG ANALYSIS AND A/D CONVERSION CAPABILITY

One-Third Octave Analysis System
- Frequency Bands: 39 one-third octave frequency bands, 3.15 to 20 KHz
  13 octave bands, 4 Hz to 16 KHz
  1 overall band
- Filter Characteristics: One-third octave conforms to USASI S1, 11, 1966, Class III
  Octave filters conform to USASI S1, 11, 1966, Class II
- Integration Times: 1/8, 1/4, 1/2, 1, 2, 4, 8, 16 and 32 seconds
- Input Voltage: 1.0 V rms full scale - all data to be analyzed is normalized to this level
- Dynamic Range: -60 dB from full scale
- Attenuators: Individual attenuators are available for gain adjustment in 1 dB steps from +25 dB to -25 dB relative to nominal 0 dB gain for each filter
- Computer Interface: Interface with ITI 4900 A/D system providing added flexibility and capability

ITI 4900 A/D System
- Word Size: 11 or 14 bits plus sign bit
- Maximum Input Voltage: ±2.50 VDC
- Aperture Time: 50 nanoseconds
- Maximum Sampling Rate: 30K samples per second, buffered input to prevent loss of data
- Output: 7 or 9 track computer compatible digital tape

Dual Channel	Typical Usage
Cross Correlation	Time correlation between data from related pickups such as input/output etc. for all types of dynamics data.
Coherence	Frequency correlation between data from related pickups for all types of dynamics data.

The specifications and photograph of the digital analysis process is shown in Table 8 and Figure 14.

4. DATA PRESENTATION

The last step in dynamics data analysis is to present the results of the analysis in a concise, easily understandable graphic form. Plots of data computed digitally greatly increase the overall interpretability of the results and permit comparisons with similarly computed data. Plots are required for immediate decision making regarding the need for further analysis, testing, and presentation of the results in a final report. Because of the versatility of the digital analysis system, customized programs are written for the user's particular requirements. The specifications of the plotting processes are shown in Table 9.

Figure 13. Analog-to-Digital System

TABLE 8

SPECIFICTIONS FOR DIGITAL ANALYSIS EQUIPMENT

RAYTHEON 704 PROCESSOR

Hardware - 32,768 word (16 bit) core
1.0 microseconds cycle time
16 priority interrupt levels
Array transform processor
Hardware bootstrap
Hardware multiply/divide

Software - Real-time operating system
Real-time Fortran IV
Batch processing
File oriented I/O
Sort/merge and FFT packages

Tektronics 4012 CRT

Card Reader
1000 cards/minute

Line Printer
245-1110 lines per minute

Disc Drive
1,280,000 word storage
20 millisecond average access time

Magnetic Tape Drive (7 and 9-track, one each)
Speed: 150 inches/second
Density: 200, 556, and 800 CPI

Figure 14. Digital Analysis System

TABLE 9

SPECIFICATIONS FOR DATA PRESENTATION EQUIPMENT

TI 4900 - CALCOMP 563 Plotting System

Ink Type
Plot Size: Width - 11 to 35 inches
Length - 100 feet
Data Input: Magnetic tape, paper tape, cards, keyboard
Resolution: 0.01 inches
Typical Plot Time: 3 to 4 minutes per plot

Gould High-Speed Plotter

Electrostatic type, on-line to Raytheon Computer System
Plot Size: Width - 11 inches
Length - 100 feet
Resolution: 0.0125 inches
Typical Plot Time: 1 second per plot

SECTION IV

LABORATORY TESTING CAPABILITY

In addition to the data acquisition and analysis capability (Sections II and III), the VIAER Facility has the capacity to obtain dynamics measurements in the laboratory on components and subsystems. It provides laboratory equipment and expertise to meet the Air Force's dynamics testing needs.

New methods are developed for determining linear and angular structural responses to mechanical, acoustic, and unsteady aerodynamic vibratory excitations. The VIAER Facility personnel also have the responsibility for developing new aircraft ground vibration testing methods prediction techniques, and design criteria for the selection of active and passive vibration isolation techniques to control response of advanced components on laser systems and large space structures. Joint programs are conducted with other Air Force and DoD organizations in preventing or resolving vibration problems.

1. VIBRATION EXCITER SYSTEM

The aircraft vibration exciter system consists of six electrodynamic exciters, power amplifier and field supply chassis, and a master control console. Special emphasis is placed on long stroke, low frequency operation with minimal damping. All components are DC coupled except the oscillators. This permits very low frequency operation without phase shift. Since the exciters have no flexures, damping is minimal.

The control console contains the master power and decay control, and individual exciter power, phasing and decay controls. Continuously, variable phase and gain controls for each exciter are contained in the control console. A master gain control is also available.

A sine sweep oscillator with a seven segment servo programmer is used as signal source for the system. An additional low frequency function generator is contained within the system for very low frequency signals and a computing counter is available for frequency determination. Acceleration and force signals are available on a patch panel for display on an eight-channel memory oscillopscope.

The master decay switch contains an adjustable time which allows the Oscilloscope trace to be triggered before the system decay is activated. This allows several complete cycles of the signal to be displayed before shut down, thereby facilitating log decrement calculations.

Primary power for the system is 208 VAC, 3-phase, 4-wire, and 60 amps per phase with all exciters operating at rated output. Specifications and a photograph of the vibration exciter system are contained in Table 10 and Figure 15, respectively.

2. VIBRATION TEST SYSTEM

The 12,000 lb force vibration test system is for general purpose testing. It is a complete operating system which includes the electro-dynamic shaker, control console, power amplifier, and field power supply. This air-cooled shaker system has a single turn, flat-ribbon moving-coil assembly. This construction technique is considered to provide a much more rigid mechanical system than the conventional configuration.

The vibratory test system is used as an experimental tool for accomplishing both basic and applied research. The efforts are in conjunction with extensive in-flight dynamics environmental studies conducted to verify prediction techniques derived directly from work of this type. The specifications for the vibration test system are shown in Table 11.

3. FOURIER ANALYSIS SYSTEM

The Fourier Analyzer is an integral part of the laboratory testing capability. It is a low-frequency digital analyzer capable of providing frequency domain analysis of complex time signals in the range of DC to 50 KHz. Its powerful measurement capacity, versatility, and keyboard

TABLE 10

SPECIFICATIONS FOR VIBRATION EXCITER SYSTEM

Unholtz-Dickie Model TA100-4

Exciter, Model 4, electrodynamic
- Stroke: 4 inches, peak-to-peak
- Force: 75 lb peak
- Frequency Range: 0 to 1000 Hz
- Armature Suspension: linear ball bearings
- Weight: 220 pounds

Power Amplifier, Model TA100
- Configuration: solid state, DC coupled
- Power Output: 1500 VA
- Feedback: current proportional to force

Phase Control, Model CAP8
- Configuration: 0° or 180°, or continuously variable 0° to 360°
- Resolution: ±0.3°
- Phase Frequency Response: within ±3°
- Amplitude Frequency Response: ±0.5 dB

Servo Programmer, Model SP-7
- Configuration: seven-segment; acceleration, velocity, and displacement selection for each segment
- Frequency Range: 5 Hz to 10 KHz
- Compressor Range: 0 to 70 dB
- Compressor Speed: 10 to 3000 dB per second

Sine-Sweep Generator, Model OSC-1S
- Frequency Range: selectable, 2 Hz to 2 KHz, 5 Hz to 5 KHz
- Frequency Sweep: selectable, linear or log
- Sweep Time: continuously variable, from 1 minute to 99.9 minute per sweep in 0.1 minute intervals
- Distortion: less than 0.5%

Low Frequency Generator, Hewlett Packard Model 330CA
- Frequency Range: 0.01 Hz to 100 KHz
- Distortion: less than 1

Computing Counter, Hewlett Packard Model 5323A
- Frequency Range: 0.125 Hz to 20 MHz
- Frequency Determination: based on reciprocal of signal period
- Measurement Time: 0.01 sec. to 4 sec., selectable in 8 steps

Oscilloscope, Tektronix Model R5103N/D13
- Viewing Area: 4" x 5", 20 sq in
- Storage: bi-stable split screen
- Writing Speed: 200 divisions per millisecond

TABLE 10 (Concluded)

Vertical Plug-In, 2 each, 4 channel, Model 5A14N
    Configuration: AC or DC coupled
    Frequency Range: DC to 1 MHz

Time Base Plug-In, Model 5B12N
    Sweep Rates: 1 microsecond to 5 seconds per division
    Triggering: AC or DC coupled, internal or external

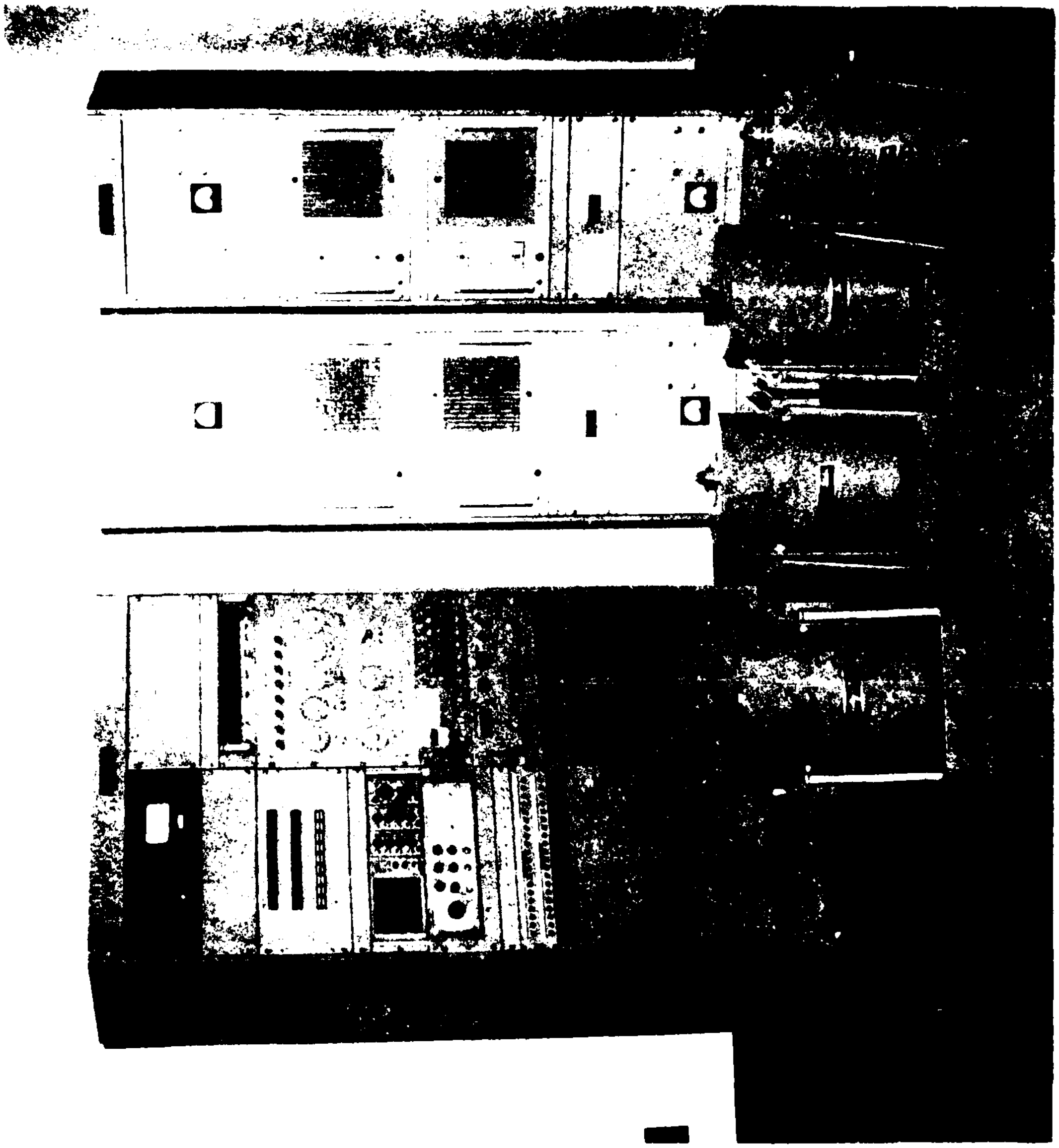

Figure 15. Vibration Exciter System

TABLE 11

SPECIFICATIONS FOR THE VIBRATION TEST SYSTEM
UNHOLTZ-DICKIE - TA130A-120 IAR

System Performance:
Generated force, continuous duty:
Sine - 0 to 12,000 lbs vector
Random - 0 to 22,000 lbs instantaneous peak and 7,000 lbs rms random with 350 lbs nonresonant table load or more with flat acceleration PSD 20 to 2,000 Hz

Frequency range: 5 to 3,000 Hz with manual operation 5 to 2 KHz

Vibration Levels vs Frequency
For mass loads up to 56 pounds
0.07 inch to 79g crossover
0.07 inch 5 Hz to 2000 Hz
79g 147 Hz to 2,000 Hz
0.5 inch 5 Hz to 21 Hz
0.7 inch 5 Hz to 15 Hz

For mass loads up to 161 pounds
0.12 inch to 47g crossover
0.12 inch 5 Hz to 88 Hz
47g 88 Hz to 2,000 Hz
0.5 inch 5 Hz to 21 Hz
0.7 inch 5 Hz to 15 Hz

For mass loads up to 345 pounds
0.2 inch to 27g crossover
0.2 inch 5 Hz to 50 Hz
27g 50 Hz to 2,000
0.5 inch 5 Hz to 21 Hz
0.7 inch 5 Hz to 15 Hz

System Components:
Shaker
Force ratings
Sine - 12,000 lbs peak
Random - 7,500 lbs rms with 22,500 lbs instantaneous peak

control make it an ideal solution for measurement problems in mechanical vibration analysis, signature and modal analysis, acoustics, control system analysis, and communication.

The Fourier Analyzer is an up-to-date software-based system. It is a completely integrated system consisting of a minicomputer for digital processing, a keyboard for overall control, an analog-to-digital converter, a display control unit and CRT, a system terminal, and operating software package. It is a fully calibrated multi-purpose system for data acquisition, data storage, and data analysis. Its uniqueness lies in its ability to implement digitally a Fast Fourier Transform quickly and efficiently. The specifications and photograph of the Fourier Analyzer are contained in Table 12 and Figure 16, respectively.

The three frequency domain techniques of power spectrum, transfer function, and coherence function are fundamental to spectrum analysis. Wide-band and narrow-band analysis can be applied to the frequency domain functions. Although the source of the data or the final result may differ from one application to another, these functions form the basis for understanding and solving complex dynamic problems.

4. RANDOM CONTROL/MODAL ANALYSIS SYSTEM

The Random Control/Modal Analysis System is a computer-controlled system for vibration exciter control. The system can be programmed for swept-sine, broad-band random, sine on broad-band random, or narrowband random on broad-band random. The system continuously corrects and modifies the spectrum being output to the exciter system as a function of feedback from the exciter to maintain the programmed function (acceleration, force, etc). The operator may intervene to keep from damaging a test component or fixture and can set any abort limits necessary such that the system will shut down automatically. In addition, 16 auxiliary abort lines can be used to trigger shutdown from external signals.

TABLE 12

SPECIFICATION FOR THE FOURIER ANALYSIS SYSTEM ANALOG-TO-DIGITAL CONVERTER
HEWLETT-PACKARD MODEL 5451B

Input Ranges: ±0.125V to ±8V peak in steps of 2

Input Coupling: DC or AC

Resolution: 10 bits including sign, 12 bits optional

Sample Rate:
Internal Triggering: 200 KHz max (1 to 4 channels simultaneously)
External Triggering: 300 KHz max (with 2-channel, 10-bit ADC)

Internal Clock Accuracy: ±0.01%

DISPLAY UNIT

VERTICAL SCALE CALIBRATION: Data in memory is automatically scaled to give a maximum on-screen calibrated display. The scale factor is given in volts/division, or in dB offset.

Linear Display Range: ±4 divisions with scale factor ranging from 1×10^{-512} to $5 \times 10^{+512}$ in steps of 1, 2, and 5.

Log Display Range: 80 dB with a scale factor ranging from 0 to -998 dB. Offset selectable in 4 dB steps.

Digital UP/DOWN Scale: Allows 8 up-scale and [illegible] down-scale steps (calibrated continuous scale factor)

HORIZONTAL SCALE CALIBRATION:
Linear Sweep Length: 10, 10.24, or 12.8 divisions

Log Horizontal: 0.5 decade/division

Markers: Intensity markers every 8th or every 32nd point

BASE SOFTWARE

TRANSFORM ACCURACY: The expected rms value of computational error introduced in either the forward or inverse FFT will not exceed 0.1% of the peak value of the transform result for block sizes up to and including 1024.

DYNAMIC RANGE: 80 dB for a minimum detectable spectral component in the presence of one full scale spectral component after eight ensemble averages for a block size of 1024.

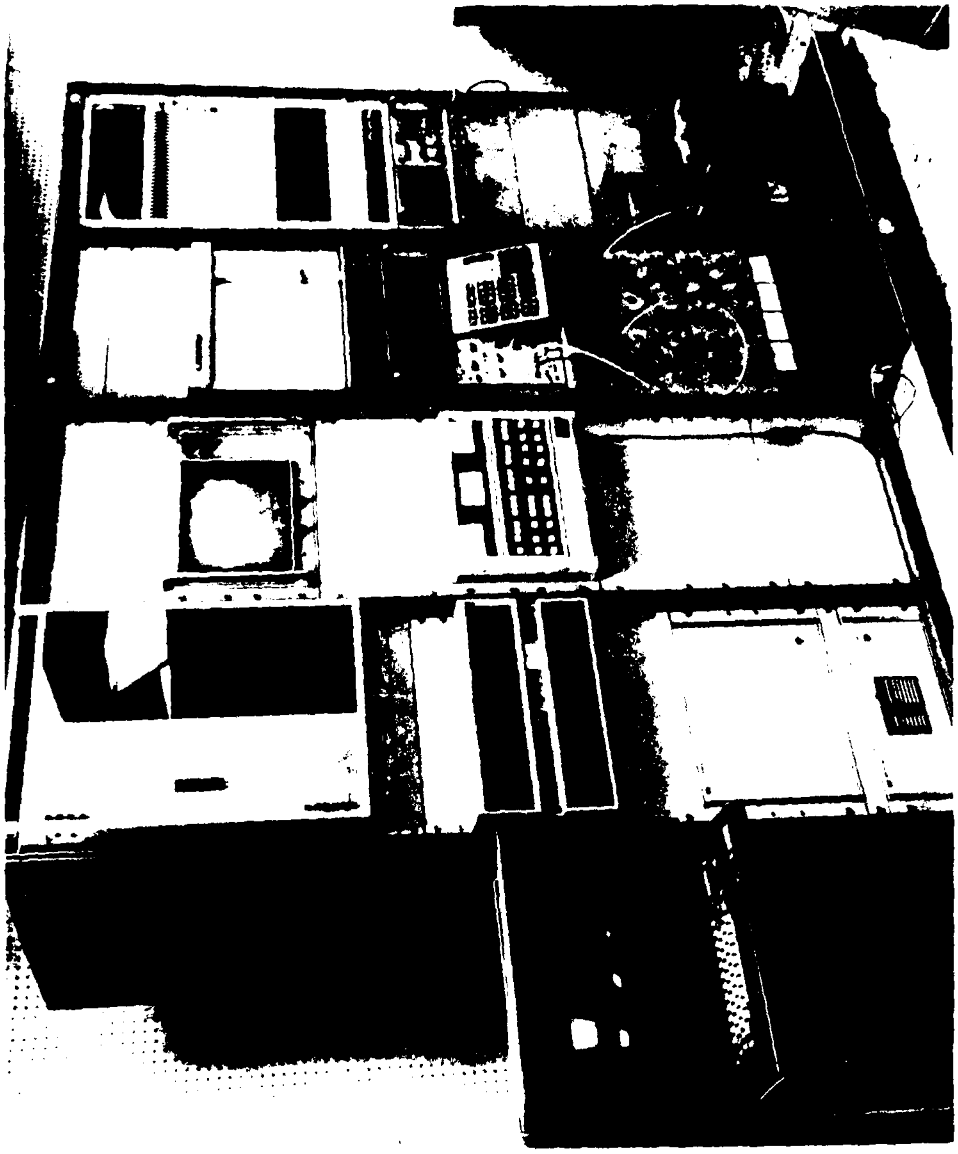

Figure 16. Fourier Analysis System

The modal analysis operation of the system is geared to defining mode shapes, natural frequencies, and damping of a component or system. The analysis can be accomplished with impact, sine or random excitation techniques. In all cases, a reference transducer and roving transducer are used from which a transfer function is computed to maintain control levels. The natural frequencies, damping, and an animated mode shape can be displayed on the CRT with hard copy capability for documentation. This system synthesizes modeling capabilities for dynamic modeling of the specimen or structure. The specifications, block diagram, and photographs of the Random Control/Modal Analysis System are shown in Table 13 and Figure 17.

5. SMALL ACOUSTIC TEST CHAMBER

The small acoustic test chamber of the VIAER Facility will accommodate small specimens in a one-foot square progressive wave section at maximum sound pressure levels of 174 dB (reference: 0 dB - 0.00002 Pa). Large specimens can be installed in an 800-cubic foot termination chamber at reduced sound pressure levels. This chamber is equipped with two sirens that produce a maximum output of 50 kilowatts, with other performance characteristics. The chamber may be equipped with a 30-kilowatt air modulator which is capable of operating in a sine wave mode, a narrow-band random mode, or a wide-band random mode. With any of the noise generators, heating is available to provide specimen temperatures to 1400°F.

The instrumentation system for the small test chamber provides 28 FM recording data channels. Data processing is accomplished through the data analysis center within the VIAER Facility. Specifications and a drawing of the small acoustic test chamber is shown in Table 14 and Figure 18.

6. WIDE-BAND NOISE TEST CHAMBER

The wide-band test chamber is powered by either of two types of noise generators. The 12-kilowatt wide-band siren is capable of producing a

TABLE 13

SPECIFICATIONS FOR RANDOM CONTROL/MODAL ANALYSIS SYSTEM

System Computer, PDP 11/35

Core Memory: 28K

Disk Storage: two 1.2 million word cartridge disk drives

Tape Storage: 9 track standard digital drive, 45 ips

Analog Input: 2-channel, 12 bit A/Ds, AC or DC coupled

Sample Rate: program selectable to 200 KHz

Antialiasing Filters: 8-pole Butterworth, 10 Hz to 50 KHz, selectable under program control

Sample Modes: buffered or non-buffered

Arithmetic: 16-bit floating point FFT, 32-bit full floating point for autopower spectrum

Frequency Control: 0 to maximum of 10 KHz with up to 512 discrete control bands

Digital to Analog Converter: 12 bits, ±10 volts full scale

Typical Loop Response Time: 1.4 seconds, 256 lines, 2500 Hz bandwidth

Types of Control: swept sine, random, sine on random, random on random; sine on random allows up to 4 sine waves (each specified by frequency and GRMS level) on broad-band random background of specified GRMS level

Modal Analysis: single and multidegree curve fitting, synthesis, modal parameter estimation, and mode shape display utilizing transfer function with zoom transform

Display Capabilities: CRT with keyboard input, hard copy output

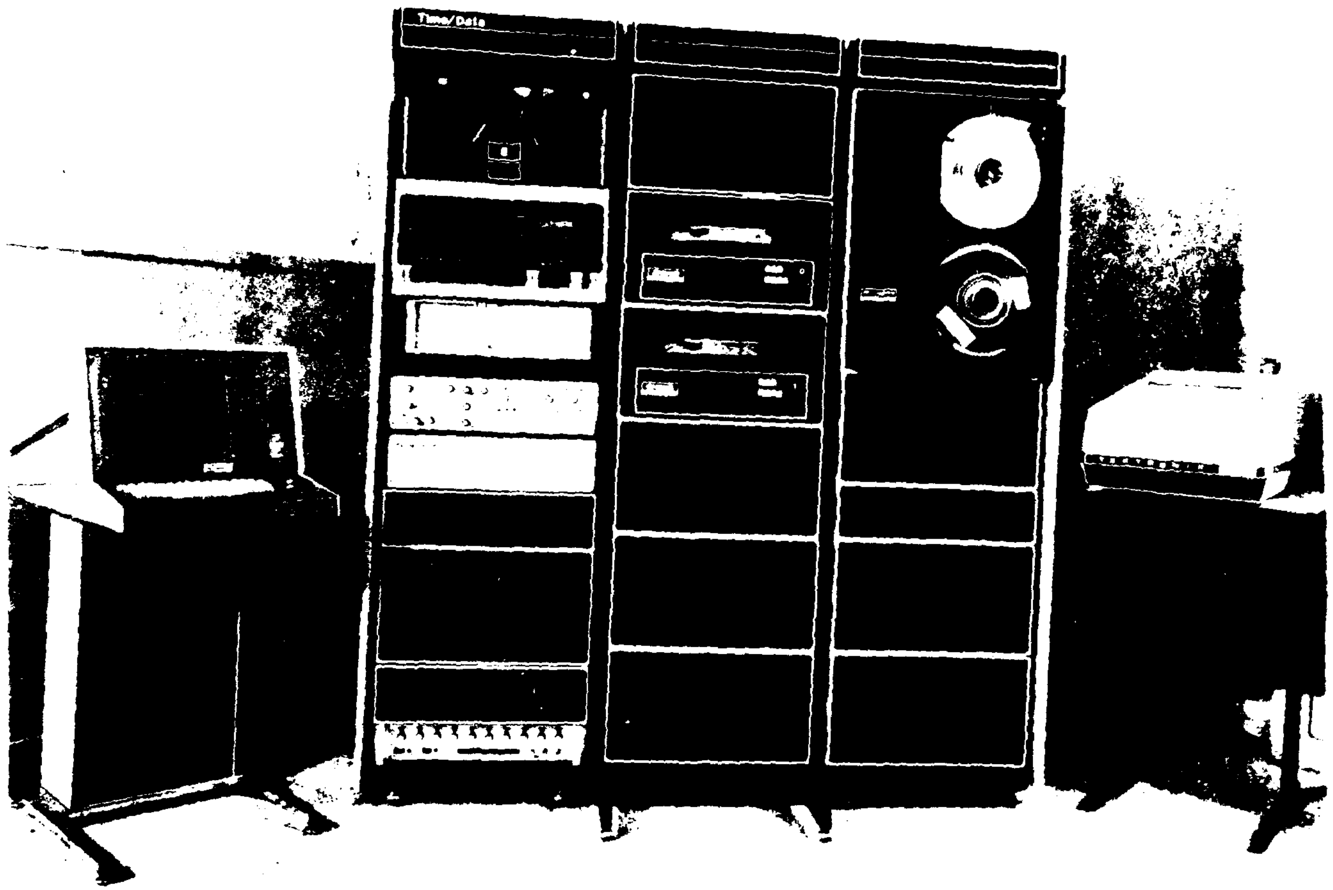

Figure 17. Random Control/Modal Analysis System

TABLE 14

SMALL TEST CHAMBER SPECIFICATIONS

Air Supply is 10,000 scfm at 3 x atmospheric pressure

1' x 1' progressive wave test section

Low frequency siren (50 Hz to 2,000 Hz; 40 kilowatt acoustic power)

High frequency siren (500 Hz to 10,000 Hz; 10 KW acoustic power)

30 KW air modulator

Maximum sound pressure level of 174 dB in progressive wave test section

Discrete frequency, narrow-band random, or wide-band noise

Maximum panel size of 1' x 1½' in progressive wave section

Termination chamber is 15' long x 8' wide x 7.5' high

Door size is 39" x 85"

48 channels of data on a continuous basis

96 channels of data on a time-shared basis

Specimens can be heated to temperatures of 1400°F

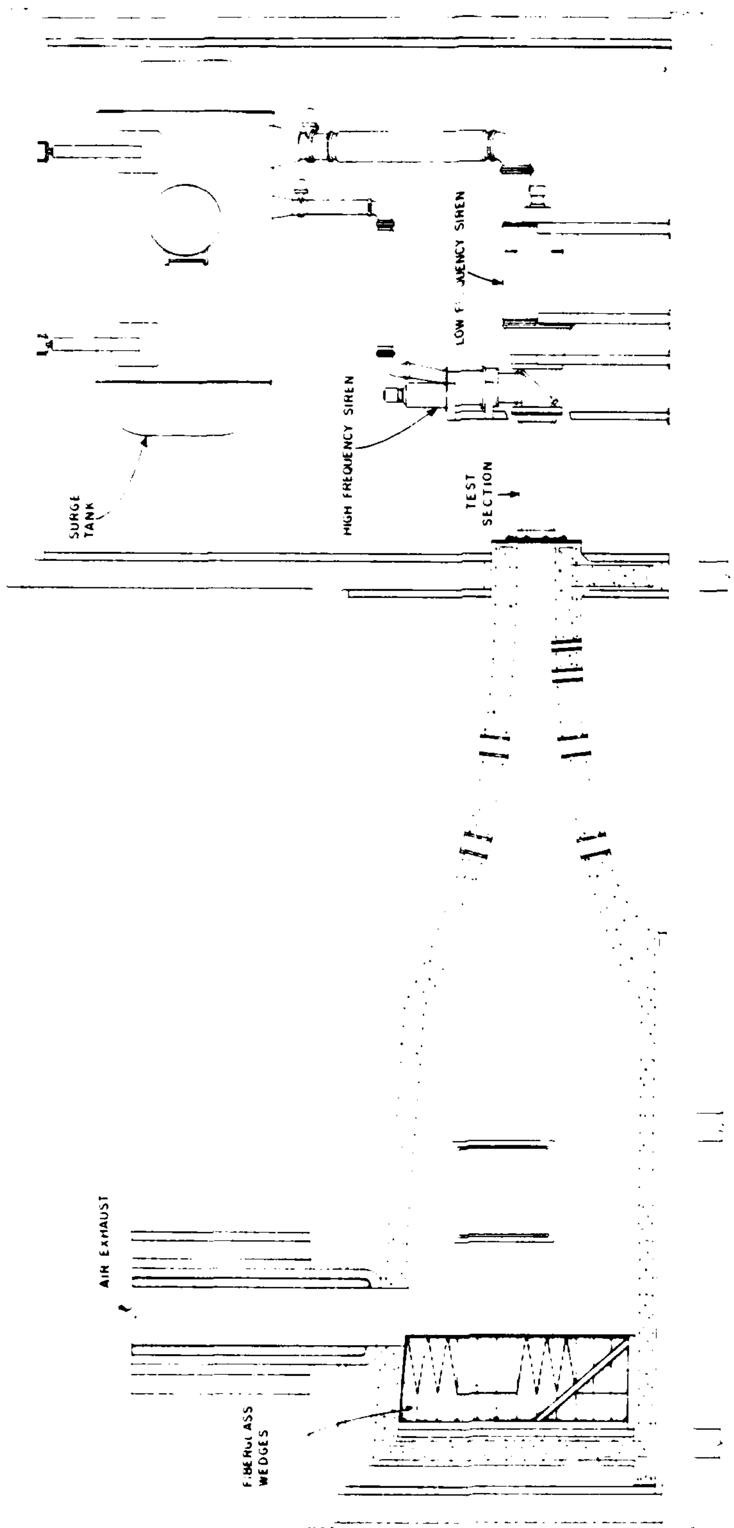

Figure 18. Small Test Chamber

continuous spectrum over the frequency range of DC to 10 KHz approximating the noise field of a jet or rocket engine. The chamber can also be powered by two 30-kilowatt air modulators, capable of operating in a sine wave mode, a narrow-band random mode, or a wide-band random mode. A maximum sound pressure level of 165 decibels (reference: 0 dB = 0.00002 Pa) can be attained at the siren horn mouth. The test chamber, also referred to as the quarter-scale facility, is suitable for a variety of experiments. These include structural component sonic fatigue testing. reliability tests of electronic equipment, and combined environments investigations. Data from this chamber is acquired through the control room's 48-channel recording systems. The test chamber specifications are contained in Table 15 and illustrated drawing of the system in Figure 19.

TABLE 15

WIDE - BAND TEST CHAMBER SPECIFICATIONS

Air supply is 10,000 scfm at 3x atmospheric pressure

Chamber is operated in a reverberant mode

Wide-band noise from siren (50 Hz to 10,000 Hz)

Two 30-kilowatt air modulators capable of discrete frequency narrow-band random, or wide-band noise operation

Maximum sound pressure level of 165 dB

Average physical dimensions of the chamber are 14' wide x 17.5' long x 10.5' high

Door size is 60" x 80"

Data from the chamber is routed through the 48-channel system continuous, 96-channel time-shared

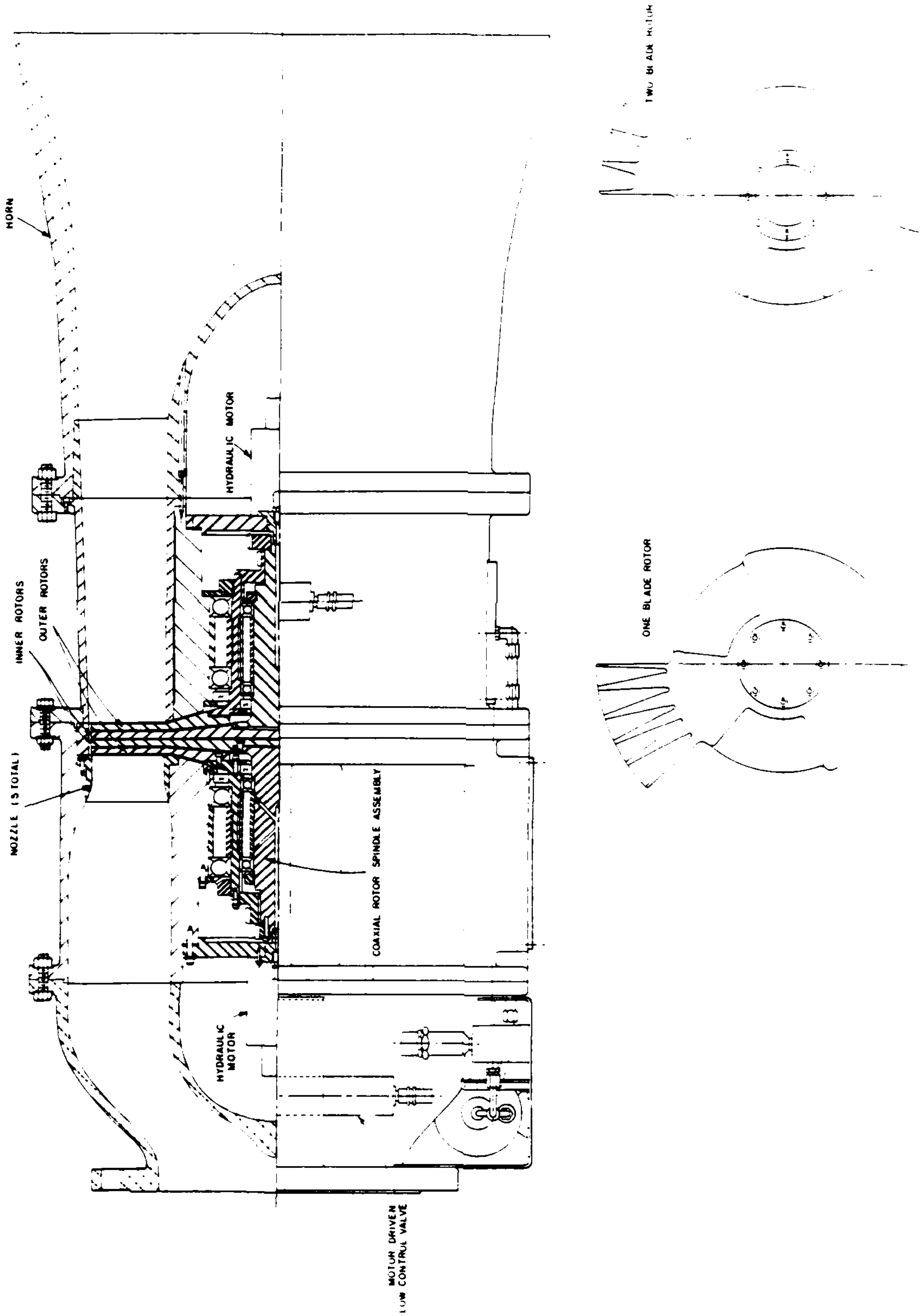

Figure 19. Wide-Band Test Siren

SECTION V

PROPOSED VIAER FACILITY IMPROVEMENT

The capability of the VIAER Facility is being continually upgraded. Presently, three areas are being investigated: angular vibration transducers, improved automatic gain changing amplifiers, and the application of Pulse Code Modulation (PCM) technology to aircraft dynamics data acquisition.

1. ANGULAR VIBRATION TRANSDUCER

The development of angular transducers for measuring low level angular vibration on Air Force aircraft, weapon systems, and structures up to 2 KHz is programmed for the future. Since little is known about angular vibration on Air Force systems, the object of this effort is to design, develop, and test a miniature angular vibration transducer which can be used in airborne environments. State-of-the-art angular transducers will be investigated to determine performance capabilities and detailed design factors. Existing empirical data, material parameters, and theoretical performance limits of different designs shall be considered. Goals and factors include: (1) small size (2" cube), (2) high resolution 10^{-9} to 10^{-6} radians), (3) wide frequency range (near DC to 2 KHz), and (4) suitability for use in airborne environments. Based on results of trade-off studies of the above factors, the most promising design approach will be selected. A prototype transducer will be constructed and subjected to environmental and performance tests. Using these test results, the design will be refined, and an improved design transducer will be fabricated and subjected to environmental and performance tests. Reference papers covering angular vibration measurements are "Angular Vibration Techniques" by P. Wayne Whaley and Michael W. Obal in the September 1978 issue of The Shock and Vibration Bulletin and "Measurement of Angular Vibration Using Conventional Accelerometers" by P. Wayne Whaley and Michael W. Obal in the September 1977 issue of The Shock and Vibration Bulletin.

2. IMPROVED AUTOMATIC GAIN CHANGING AMPLIFIERS

This program is concerned with the design, development, and testing of automatic gain changing amplifiers. The objective of this program is to develop an improved automatic gain changing amplifier suitable for use in laboratory, ground, and flight applications. It will require detailed investigations in the application of hybrid technology to the design of such a device. Trade-off studies will be required wherein both theoretical and physically implementable design parameters shall be considered with respect to the desired performance goals. Using these results, the most promising design approach will be selected and a prototype amplifier constructed. This amplifier will then be subjected to extensive environmental performance testing to determine potential problems and/or performance degradation. Using these results, the design will be revised and an improved amplifier will be constructed and tested. The effects of environmental parameters such as temperature and vibration will be considered. Among other parameters to be given consideration are size, power consumption, drift, signal-to-noise ratio, dynamic range, and reliability. This effort is proposed for fiscal year 1982.

3. APPLICATIONS OF PULSE CODE MODULATION (PCM) TECHNOLOGY TO AIRCRAFT DYNAMICS DATA ACQUISITION

These findings represent the results of a contracted design study for an inflight dynamics data system employing PCM. The study was performed by McDonnell Aircraft Company (MCAIR) and was divided into four phases:

Phase I - Facility review, literature search, formulation of system standards, and systems goals.

Phase II - Definition of PCM systems.

Phase III - Evaluation of PCM systems.

Phase IV - PCM System Design.

In order to solve vibration and noise related problems in complex aircraft structures, 100 or more simultaneously-acquired accurate measurements from different locations are frequently required. Analytical tools have been available for some time to solve complex structural problems, along with a computer facility of sufficient capability to handle the data.

The PCM system design was optimized for the goals and requirements of the VIAER Facility. It includes an airborne PCM acquisition and recording system, and a ground system for playback, editing, and analysis. Key features are the ability of the airborne system to acquire and record data up to 20 KHz from 144 analog transducers simultaneously for eight hours, and sufficient computer power and memory capacity in the ground system to process the large amount of resulting data (approaching a maximum of 10^{11} bits recorded per flight). On-board tape recording is the only practical means of storing such large quantities of data acquired in flight tests and at various remote field sites for later processing at the VIAER Facility.

The airborne PCM encoder/formatter system and its associated ground support equipment will require approximately four years of detailed design and development activity in order to be realized. The maximum data rate capacity of this system will be approximately 154 megabits per second (48 serial streams of 3.2 megabits per second each). This exceeds that of existing aircraft flight test PCM system by two orders of magnitude.

The ability of existing tape recorders and tape to absorb data at the above rate and reproduce it with a satisfactory bit error rate performance can best be determined by experiment. Therefore, prior to initiating development of the airborne system, it was recommended that a tape recorder/reproducer evaluation be performed. A PCM simulator and a bit error detector will be needed for this evaluation.

The ground support equipment to be developed consists of a Format Memory Programmer (for set-up of the airborne system), an Integrated Test Set (used for checkout and maintenance of the system), and a Quick-Look Test Set. Other hardware items that are not off-the-shelf (and therefore requiring development) include a multiple decommutator and computer interface and a high speed bus converter interface between the computer and array processor.

The recommended ground processing system to be installed in FY82 consists of a Digital Equipment Corporation (DEC) VAX 11/780 computer, a Floating Point Systems, Inc. AP180V array processor, and associated peripheral equipment. This system would replace VIAER Facility's current Raytheon 704 system which is insufficient to manage the increased amount of source data acquired by the new airborne system.

In addition to the hardware, considerable new software development is required to support new features of the ground processing system. Some software development will also be needed for the Format Memory Programmer and Integrated Test Set.

SECTION VI

CONCLUSIONS

The VIAER Facility is a powerful and unique tool within the Air Force for defining the dynamics characteristics of aircraft, missiles, spacecraft, and ground support equipment. A dynamics data bank has been established to aid aircraft and equipment designers in research and development efforts. The Facility also participates in many joint efforts with system program offices. Better knowledge of noise, vibration, and other dynamics phenomena occurring during operational conditions will remove many of the current controversial philosophies and concepts which are due to lack of sufficient and accurate data.

APPENDIX

DYNAMICS TEST PLAN OUTLINE

1. Technical assistance by the Flight Dynamics Laboratory is obtained by an official letter of request to the Director (AFWAL/FI). A description of the problem as complete as possible given the current state of the evidence should be included as an attachment to this letter. Both common sense and past experience indicate that personnel in the affected system office are in a far better position to describe the problem and all its ramifications than are the AFWAL/FI engineers temporarily assigned to accomplish the project. Accordingly, this problem description will normally serve as the first section of the final technical documentation of the experimental dynamics investigation, and its author will be included as a co-author of the full report. As an aid in organizing this information, a suggested Format for Problem Description is attached. This format also serves as a check-off list for the types of information to be included. Of course, not all of these items will be applicable to every project.

2. The problem description is used by AFWAL/FI engineers to prepare a Test Plan for carrying out the measurements and data analyses required for each of the joint system projects. This test plan is the technical part of the documentation that must be approved by both the requesting office and AFWAL/FI before any work can be undertaken. For your convenience, a copy of the Test Plan Format is also attached. System personnel who are cognizant about any of the topics included may wish to provide guidance to the AFWAL/FI project engineers preparing the test plan. Such guidance may range from informal telephone comments to actual drafting of parts of the test plan itself. The optimum number of measurements and degree of analysis are not always physically possible or economically feasible. Consequently, free communication on these matters is necessary to achieve the best design of the test plan. The approved test plan will normally follow the problem description as the second section of the final technical documentation of the joint system experimental effort.

FORMAT FOR PROBLEM DESCRIPTION

I. IDENTIFICATION OF PROBLEM

1. Statement of the problem, its general nature and character. Definitions of any special terminology employed.

2. Photographs showing manifestations of the problem. Descriptive terms for features shown in photographs.

3. Data confirming any malfunctioning of the system. Dimensions and source of qualitative measures.

4. Evidence indicating the existence of present or potential problems.

5. Character of evidence and its direct and indirect relation to the problem.

II. CHRONOLOGY OF THE PROBLEM

1. Origin of problem. What first signaled its existence?
2. Growth of problem. How has it become more serious?
3. Remedial measures taken to alleviate or bypass the problem.
4. Improvements resulting from remedial measures.
5. New problems introduced by remedial measures.

III. EXTENT OF PROBLEM

1. Subsystems and functions intrinsic to the problem.

2. Adjacent subsystems and analogous functions that are apparently extrinsic to the problem.

3. Structures or components requiring replacement or repair.

4. Mechanisms or circuits requiring realignment or recalibration.

5. Fluids or gases requiring excessive refills or repressurizations.

IV. IMPACT OF PROBLEM

1. Lost capabilities and functions of the system.
2. Diminished performances and efficiency of the system.
3. Abnormalities not related to system performances.
4. Increased down-time for maintenance or repair.
5. Extended demands on operating and support personnel.
6. Higher cost of system operation and mission achievement.
7. Other impacts either adverse or favorable.

V. TECHNICAL REQUEST TO FLIGHT DYNAMICS LABORATORY

1. Types of measurements: strain, acceleration, pressure, etc.
2. Locations where sensing devices should be placed.
3. Test conditions when measurements should be recorded.
4. Types of data analysis desired.
5. Expected use of the results of this measurement project.
6. Consequences expected if this measurement project cannot be carried out by the Flight Dynamics Laboratory.

TEST PLAN FORMAT - Brief Form

I. OBJECTIVES

1. Statement of the problem
2. Engineering analysis of the problem
3. Objectives of measurement program

II. TEST DESIGN

1. Measurement desired
2. Analysis methods desired
3. Statistical models desired

III. INSTRUMENTATION

1. Transducers and sensors
2. Signal conditioning equipment
3. Magnetic tape recording

IV. DATA ACQUISITION

1. Test site operations
2. Sensor location descriptions
3. Test condition description

V. DATA ANALYSIS

1. Overall rms magnitudes and probability densities
2. Amplitude spectra, spectral and frequency response functions

VI. STATISTICAL MODELS

1. Theoretical models from system dynamics theory

2. Empirical models from experiences with similar systems

3. Spectral profiles as linear combinations of a few base profiles

4. Spectral data as functions of locations and test conditions measurements

5. Regression model using quantitative test condition measurements

6. Analysis of Variance model using qualitative sensor location characteristics

VII. DOCUMENTATION OF RESULTS

1. Problem Description

2. Test Plan

3. Instrumentation

4. Data Acquisition

5. Data Analysis

6. Statistical Models

7. Engineering Evaluation

8. Conclusions and Recommendation

9. Appendix

TEST PLAN FORMAT

I. OBJECTIVES

1. Statement of the Problem

a. System, structures, and functions involved

b. Origin, extent and consequences of problem

c. Attempted fixes and their shortcomings

2. Engineering Analysis of the Problem

a. Hypothesized explanation considered most likely

b. Alternative explanations consistent with facts

c. Compare/contract hypothetical and alternative explanations

3. Objective of Measurement Program

a. Estimating the dynamics environment of a system

b. Estimating coherences and frequency response functions

c. Estimating effects of varying sensor locations and test conditions

d. Testing of theoretical or empirical prediction functions

e. Testing the hypothesized explanation of the problem

f. Testing the alternative explanations of the problem

II. TEST DESIGN

1. Measurement Desired

a. Type of Measurement: strain, velocity, acceleration, pressure, etc.

b. Criteria for locating sensing devices

c. Criteria for selecting test conditions

d. Criteria for choosing size and sampling rate

2. <u>Analysis Parameters Desired</u>

a. Averaging time for overall root mean square magnitudes

b. Interval size or number of interval for histograms

c. Frequency range, bandwidth, and number of transforms for spectral data

d. Time length and time interval for correlation data

e. Linear or log scales for abscissa and ordinate of plots

f. Output and input channels for frequency response functions

g. Output, input, and conditioning channels for multiple and conditional types of coherence functions and frequency response functions

3. <u>Statistical Models Desired</u>

a. Theoretical models from system dynamics theory

b. Empirical models from experience with similar systems

c. Spectral profiles of a specific linear combination of a few base profiles

d. Spectral densities as functions of locations and test conditions

e. Location effects as functions of location variables

f. Test condition effects as function of test condition variables

III. INSTRUMENTATION

1. Transducers and Sensors

a. Analog transducers: piezoelectric, thermoelectric, photoelectric, electrokinetic

b. Analog sensors: variable resistance, capacitance, inductance, and transformer types

c. Frequency generating transducers

d. Frequency modulated sensors

e. Pulse counters

f. Digital encoders and encoder transducers

2. Signal Conditioning Equipment

a. Voltage and power amplifiers

b. DC to AC modulators

c. Computing and gating circuits

d. Analog-to-digital converters

e. Filters, attenuators, and impedance matching devices

3. Magnetic Tape Recording

a. Direct Amplitude Modulation

b. Frequency Modulation

c. Pulse Amplitude and Pulse Duration Modulation

d. Pulse Code Modulation

e. Digital: Return to zero or Non-return to zero

IV. DATA ACQUISITION

1. Test Site Operation

a. Duties of FDL, system, and test site personnel

b. Installation of instrumentation system

c. Engineering drawings showing instrumentation as installed

d. Photographs showing sensing devices in position

e. Recording noise floor of instrumentation system

f. Recording dynamics data and test condition information

g. Data inspection and repeat test procedures

h. Removal of instrumentation system

2. Sensor Location Descriptions

a. Axial direction: vertical, lateral, longitudinal, or inclined

b. Relative direction: perpendicular or parallel, radial or tangential

c. Form of structure: beam, plate, ring, cylinder, flat, convex concave

d. Purpose of structure: shape, cover, subdivide, support, connect

e. Orientation of structure: horizontal, vertical, inclined

f. Composition of structure: material, size, ight, and stiffness

g. Geometric location: left, right; fore, aft; upper, lower; internal, external

h. Functional location: crew, electronics, engine, fuel, cargo

3. Test Condition Description

a. Environmental variable: weather conditions during test

b. System variables: dimensions, weight, fuel load, cargo distribution

c. Operational variables: air speed, altitude, climb, roll, pitch, yaw

d. Propulsion variables: thrust, power, torque, rpm, fuel flow

e. Other variables: engine temperature and pressure, exhaust velocity and temperature

V. DATA ANALYSIS

1. Time Data Analyses - single and dual channel

a. Overall rms vibration magnitudes

b. Probability density functions

c. Auto-correlation functions

d. Joint probability density functions

e. Cross-correlation functions

2. Spectra Data Analyses - single and dual channel

a. Amplitude spectra

b. Auto-spectral density functions

c. Cross-spectral density functions

d. Coherence functions

e. Frequency response functions

3. Multiple Channel Data Analyses

a. Multiple coherence functions

b. Multiple frequency response functions

c. Conditional coherence functions

d. Conditional frequency response functions

V. STATISTICAL MODELS

1. Theoretical and Empirical Models

a. Model formula specified

b. Computation of parameters in modeling function

c. Model root mean square (rms) error

2. Spectral Profile Model - (Factor Analysis of N profiles)

a. Compute profile statistics: μ_k, σ_k, a_k, b_k, c_k, ... (k=1...N)

b. Compute base profiles: A(f), B(f), C(f),...(f=freq)

c. Model for profile $P_k(f) = \mu_k + \sigma_k \; a_k A(f) + b_k B(f) + \ldots)$

d. Model rms error

3. Measurement Model for Location/Test Condition Matrix

a. Compute constant a, location effects b_{ij}, test condition effects c_j and interaction term d

b. Model for measurement $V_{ij} = a + b_i + c_j + d\, b_i\, c_j$

c. Model rms error

4. <u>Analyses of Variance Model for Location Effects, b_i</u>

   a. Define attributes characterizing each location

   b. Compute main effects and interactions

   c. Analyses of Variance Model and its rms error

5. <u>Regression Model for Test Condition Effects, c_j</u>

   a. Define variables specifying each test condition

   b. Compute linear and quadratic regression coefficients

   c. Regression model and its rms error

VII. <u>DOCUMENTATION OF RESULTS</u>

1. .Problem Description
2. Test Plan
3. Instrumentation
4. Data Acquisition
5. Data Analysis
6. Statistical Models
7. Engineering Evaluation
8. Conclusions and Recommendations
9. Appendix

a. Test Item	Equipment specifications and other
b. Instrumentation	supplementary data not included in
c. Data Analysis	main text

Note the parallel topic headings in this test plan and documentation of results above. This is intentional since future documentation will include the reasons for any differences between original test plans and final test conduct.

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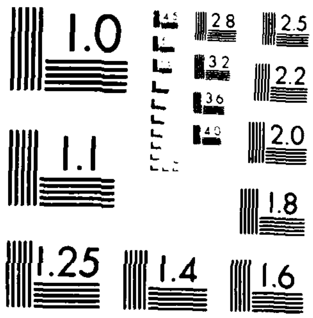
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